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A Benefit-Cost System for Chemical Pesticides

CONSAD Research Corp.

June 1975

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A BENEFIT-COST SYSTEM FOR CHEMICAL PESTICIDES

Office of Pesticide Programs
Office of Water and Hazardous Materials
Environmental Protection Agency
Washington, D.C. 20460

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A BENEFIT COST SYSTEM FOR CHEMICAL PESTICIDES

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Final Report
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PREFACE

CONSAD Research Corporation prepared this report during the period October 8, 1974 - June 30, 1975, under Contract Number 68-01-2970 for the Strategic Studies Unit, Office of Pesticide Programs, Environmental Protection Agency. Dr. John Charbonneau was the EPA Project Officer.

Mr. Ralph Kennedy, Dr. Robert Lowrey, Mr. Alan Bernstein, and Dr. Frederick Rueter were the principal CONSAD personnel assigned to this project.

Dr. Herbert Cole, plant pathologist and chemical pesticides expert, The Pennsylvania State University, and Dr. Henry F. Smyth, Jr., toxicologist and Advisory Fellow, Mellon Institute, were the principal consultants.

TABLE OF CONTENTS

Page

PREFACE ii

EXECUTIVE SUMMARY vii

1.0 INTRODUCTION 1.1

- 1.1 Purpose 1.1
- 1.2 Focus 1.1
- 1.3 Methodology 1.3

2.0 THE BIOLOGICAL BASIS FOR BENEFIT-COST ASSESSMENT OF PESTICIDE USE 2.1

- 2.1 Introduction 2.1
- 2.2 Pest Control Alternatives 2.2
- 2.3 Benefits and Costs from Pest Control 2.5
- 2.4 Measuring Benefits and Costs 2.6
- 2.5 Evaluation of a Pesticide in Terms of Parallel Comparisons with Similar Materials 2.10
  - 2.5.1 Efficacy 2.11
  - 2.5.2 General and Environmental Chemistry 2.12
  - 2.5.3 Product Hazard 2.13
- 2.6 Summary 2.14
- 2.7 References 2.15

3.0 THE ECONOMIC EVALUATION OF THE BENEFITS AND COSTS OF PESTICIDE USE 3.1

- 3.1 Introduction 3.1
- 3.2 Evaluation of Benefits and Costs 3.2
  - 3.2.1 Net Internal Benefits 3.2
    - 3.2.1.1 Perfectly Competitive Industry: Cost-Reducing Use 3.3
    - 3.2.1.2 Perfectly Competitive Industry: Price-Increasing Use 3.8
    - 3.2.1.3 Oligopolistic Industry 3.9
    - 3.2.1.4 Measurements of Net Internal Benefits 3.9

TABLE OF CONTENTS (continued)

Page

3.2.1.5 The Desirability of Marginal Production Cost Data 3.14
3.2.2 Net External Benefits 3.16
3.2.2.1 Health Benefits and Costs Accruing to Households 3.17
3.2.2.2 Health Benefits and Costs Accruing to Public Agencies 3.18
3.2.2.3 Environmental Benefits and Costs Accruing to Households 3.18
3.2.2.4 Environmental Benefits and Costs Accruing to Public Agencies 3.19
3.2.2.5 Regulatory Benefits and Costs Accruing to Public Agencies 3.19
3.2.3 The Treatment of the Displacement of Competitive Pesticides 3.20
3.2.4 Discounting Future Benefits and Costs 3.21
3.2.5 The Economic Benefits and Costs Associated with Each Category of Pesticide Use 3.23
3.3 Structure of the Benefit-Cost Submodels 3.29

4.0 THE FOOD, FEED, AND FIBER PRODUCTION SUBMODEL 4.1

4.1 Background 4.1
4.2 Net Benefits to Society from Pesticide Use 4.1
4.2.1 Acres of Crops Treated by Pesticides 4.3
4.2.2 Change in Crop Output Attributable to Pesticides 4.10
4.2.3 Change in Crop Prices Attributable to Pesticides 4.12
4.2.4 Change in Consumers' Surplus Attributable to Pesticides 4.15
4.3 Costs of Pesticide Application 4.16

TABLE OF CONTENTS (continued)

Page

5.0 THE HEALTH EFFECTS SUBMODEL 5.1

- 5.1 Background 5.1
- 5.2 Outputs of the Health Effects Submodel 5.1
  - 5.2.1 Health Damages 5.1
    - 5.2.1.1 Definition of Health Damages Based on Human Experience Data 5.6
    - 5.2.1.2 Definition of Health Damages Based on Experimental Toxicology Data 5.9
    - 5.2.1.3 Refinement and Quantification of Health Damages 5.15
  - 5.2.2 Health Benefits 5.17
- 5.3 Inputs to the Health Effects Submodel 5.18
- 5.4 Relating Inputs and Outputs of the Health Effects Submodel 5.20
- 5.5 Application of the Health Effects Submodel 5.23

6.0 THE ENVIRONMENTAL EFFECTS SUBMODEL 6.1

- 6.1 Conceptual Structure and Assumptions 6.1
- 6.2 Accumulation and Degradation Processes 6.4
  - 6.2.1 Application Rates Per Acre 6.6
  - 6.2.2 Decay Rates in Soil 6.7
  - 6.2.3 Runoff Rates 6.22
- 6.3 Biological Uptake 6.22
- 6.4 Population Damages 6.27
- 6.5 Monetary Evaluations 6.32
- 6.6 Areas for Future Work 6.32

7.0 SUMMARY OF THE BENEFIT-COST SYSTEM PROCEDURES 7.1

- 7.1 Criteria for Design of the Benefit-Cost System and Input Requirements 7.1
- 7.2 Outputs of the Benefit-Cost System 7.2
- 7.3 Calculation Procedures 7.3

TABLE OF CONTENTS (continued)

Page

APPENDIX A: Taxonomies for Alternative Pest Control Methods A. 1

APPENDIX B: Benefits and Costs from Pest Control B. 1

EXECUTIVE SUMMARY

In this report, the application of benefit-cost analysis in the registration of chemical pesticides is developed. A comprehensive benefit-cost system, designed to be used both in the registration of new pesticides, as well as in the reregistration of existing pesticides, is described. It is a workable system, not an ideal one; that is, it reflects the current state-of-the-art and it uses the presently available data. As technology improves, more data become available, and knowledge increases, components of the system can be upgraded to reflect these changes. Nevertheless, the present system is intended to provide convenient, summary formats of the most promininent indicators of benefits and costs, so that all benefits and costs, especially those which are conceptually and empirically difficult to measure -- such as long-term human health and indirect environmental effects -- are formatted and depicted in the most comparable presentation possible.

The criteria for the development of the system included:

- The system must be generally applicable over a broad range of pesticide types and uses,
- The system must contain flexibility for use with pesticides which have not yet been registered, as well as those which require a reregistration decision, and it must enable the forecasting of benefits and costs for five-year intervals,
- The system must comprehend all possible benefits and costs attributable to chemical pesticides, and
- The system must as closely as possible reflect processes that are seen in the "real-world" pesticides context, including farmers' decisions to use pesticides, the movement of residues through soil and water into the food chain, and the appearance of pesticide residues in human tissue.

These criteria had an all-pervasive effect on how the benefit-cost system was developed, especially in the sense that alternative assumptions and calculating procedures were required, depending, for example, on whether the pesticide seeking (re) registration was an agricultural or public health type, and depending on what agency or component of society bore the costs and reaped the benefits.

These alternative assumptions, or conditions, which could be imposed on the benefit-cost system, and to which the system had to be responsive, dictated that the system had to be developed on a biologically sound basis. Therefore, following an introduction to the study in Chapter 1.0, Chapter 2.0 was devoted to describing the biological basis for benefit-cost assessment of pesticide use. Four categories of pests were identified, the destruction or control of which would be the mechanism by which benefits were achieved:

- Plant pathogens: Organisms which have adverse effects on valuable plants, these effects being, called "diseases,"
- Weeds: Plants which are unwanted, and which compete with valuable plants for water, nutrients, and other life-components,
- Insects and other arthropods: Animals which feed upon or otherwise antagonize and damage plants, animals, people, natural and man-made objects, and structures, and
- Vertebrates: Animals which have the same effects in general as the insects and other arthropods.

Furthermore, the various types of pest control available to handle these pest problems were identified as follows:

- Genetic resistence, tolerance or immunity on the part of the plant or crop or other organism attacked by the pest,
- Biological control of the pest by parasites, predators or other living organisms,
- Cultural control by avoidance, water management or other techniques,

- Physical and mechanical control, and

- Chemical control.

These categories of pests and pest control alternatives are shown in detail in Chapter 2.0 and Appendix A.

The last category, chemical pesticides, was selected as the main focus of the study, and the benefit-cost approach required that users and uses of this group be identified. The users of chemical pesticides, or more specifically, those entities receiving benefits or incurring costs from chemical pesticide use, were broadly defined as follows:

- Private institutions, agency or individual,
  - Manufacturer of pesticide,
  - Formulator,
  - Distributor,
  - Wholesaler,
  - Retailer,
  - Applicator,
  - Agricultural producer,
  - Field worker,
  - Private individual.

- Public agencies,
  - Federal government,
  - State government,
  - Local government.

- Society as a whole.

- Non-human environmental components,
  - Marine aquatic,
  - Fresh water aquatic,
  - Terrestrial.

Five categories of chemical pesticide use were defined as:

- Pesticide use in food, feed, and fiber production,

- Pesticide use in health/disease vector and nuisance pest control,
- Pesticide use in commercial-industrial situations,
- Pesticide use in providing aesthetic improvement, and
- Pesticide use in providing environmental management.

Benefits received and costs incurred by the above users for each use category were then outlined. Details of this taxonomy are further explained in Chapter 2. 0 and Appendix B.

This biological basis for benefit-cost assessment of pesticide use provided support for the subsequent creation of benefit-cost matrices and analytical procedures. Thus, based upon the analysis in Chapter 2. 0, the third chapter provides an economic-theoretic basis for the use of benefit-cost concepts for analyzing pesticide use, and a three-dimensional matrix for the identification of: (1) pesticide use categories, (2) distribution of benefits and costs, and (3) the separation of benefits and costs which are internal (direct) from those which are external (indirect). The use of this matrix is to ensure the complete analysis of all benefits and costs, to aid in preventing double-counting, and to enable the identification of the agencies, entities or other components of society who receive the benefits and pay the costs of pesticide use.

Upon examining the matrices, it becomes evident that there are market uncertainties for the pesticide producer and economic, social, and environmental uncertainties for users, consumers, and society as a whole. Therefore, it was necessary to develop a series of flexible algorithms and analytic techniques that could be used in each of the pesticide use categories, when necessary. These algorithms are referred to as "submodels" in this study, and alternative techniques for quantifying each submodel are available. All submodels pertinent to a pesticide registration decision should be used.

Hence, those segments of the benefit-cost matrices developed in Chapter 3. 0 that will receive the most use during pesticide product registration decisions have been fully developed as submodels. These include the food, feed, and fiber production submodel developed in Chapter 4. 0, the health effects submodel developed in Chapter 5. 0, and the environmental effects submodel developed in Chapter 6.0. In each of these three chapters, procedures for calculating the relevant benefits and costs -- outlined in Appendix B and in the matrices of Chapter 3.0 -- are discussed, along with the data requirements and possible data sources. Overall, the models are intended to draw on existing public agency and research data, as well as data supplied by the registration process itself. With these data, a range of benefits and costs can be assessed which are likely to occur if a proposed pesticide is registered. For pesticides on which substantial historical and test data exist, the range can be made quite narrow, but in the case of very innovative and unknown chemical compositions, the range must be broadly defined as best it can be, by drawing on toxicity, persistence, and effectiveness data for similar materials and formulations.

A summary of the three submodels presented in Chapters 4.0, 5.0, and 6.0 concludes the description of the benefit-cost system. Through this summary (Chapter 7.0), the user of the methodology gets a "feel" for what the system can provide in terms of assessing benefits and costs associated with the use of a pesticide. This, in turn, allows the user to see the dimensions on which a decision concerning registration or reregistration of a pesticide product can be made.

The benefit-cost system, and in particular, the procedures developed in Chapters 4.0, 5.0, and 6.0 is then tested during an hypothetical phenoxy herbicide seeking registration for use on wheat, oats, and barley crops. The results of this case study appear in a separate volume.

It is important to recognize that the complexity of the benefit-cost calculations described in the system will differ when:

- The pesticide is proposed for reregistration instead of for its first registration,

- The pesticide is known to be highly toxic or highly persistent, relative to most other pesticides, to the extent that even moderate rates of exposure to people might have severe acute or chronic health effects, and

- The range of crops or other types of uses is either very extensive, or very narrow, with accompanying ranges of probable geographic dispersion of the pesticide.

Thus, the flexibility of the algorithms and analytic techniques comprising the benefit-cost system is crucial. Furthermore, the system is intended to be used in a decision-making context, with the systematic development of comparable calculations of benefits and disbenefits (costs) for one specific pesticide, in comparison with alternative pesticides or other pest control programs.

It is also important to point out that the analytic techniques used in each submodel are not based on detailed physical models. Data deficiencies and a lack of knowledge exist which do not allow for the development or use of such models. This is particularly true when trying to assess the health and environmental benefits and costs of a new pesticide solely from animal toxicology and other experimental data. The development of techniques whereby comparisons can be made with similar pesticides already established on the market is useful, but can give biased results. However, these comparison procedures are used, as they provide the best information available at the present time.

Continued progress in understanding the relationships between efficacy in a test situation and the expected results when a pesticide is used commercially, and between animal toxicology and other experimental data and expected human health and environmental impacts on a broad scale, can add precision to the algorithms and analytic techniques presented in this study. The methodology is a dynamic one and must be updated and improved as more knowledge and better information become available in the future.

1.0 INTRODUCTION

1.1 Purpose

In this study, the application of benefit-cost analysis in the registration of chemical pesticides is developed by:

- Presenting a taxonomy of commonly recognized pests and pest control alternatives.
- Providing a taxonomy of entities receiving benefits and incurring costs for various uses of pesticides.
- Describing a matrix of benefits and costs applicable to each pesticide use category.
- Reviewing applicable methodologies for assessing the appropriate benefits and costs.
- Developing a benefit-cost system by using flexible algorithms and analytic techniques that can efficiently measure and format the benefits and costs using available information.
- Testing the benefit-cost system using an hypothetical phenoxy herbicide as a case study.

1.2 Focus

In the development of the benefit-cost system to be used in the registration process of chemical pesticides, the focus has been on structuring a system that will be applicable to the registration of new pesticides, as well as the reregistration of existing pesticides. Furthermore, in developing the procedures to be employed in measuring benefits and costs, it was assumed that the registration or reregistration decision will be with respect to one pesticide product when used for a particular use or multiple similar uses. Therefore, specification of the use(s) of the pesticide product must be made -- e.g., the (those) crop(s) to receive the pesticide product. Then, the basic decision criterion involves a comparison of the benefits and costs associated with the use of the pesticide product in the manner specified with respect to some alternative practice. In the theoretical specification of benefits and costs, monitoring and regulating costs of the registration process are considered, but detailed computation techniques are not developed in the benefit-cost system.

Although the benefit-cost system has been developed with the above focus, the basic computation techniques can be used in other areas of pesticide regulation, for example:

- Suspect chemical review,
- Review prior to possible cancellation/suspension actions, and
- Analysis in support of ongoing cancellation/suspension hearings.

However, if this were done, the bounds of the benefit-cost analysis would change. That is, instead of analyzing the benefits and costs associated with one pesticide product when used for a particular use or multiple similar uses, the analysis may now focus on:

- All products containing a given active ingredient, or
- All products containing a given active ingredient registered for a particular use or several specified uses.

Needless to say, the benefit-cost analysis would not proceed in an identical manner. The complexity of the benefit-cost calculations would differ and the data problems may also change. Furthermore, the decision criteria would be more complex, as attempts would now be made to cancel selected uses such that net benefits are maximized. In addition, the monitoring and regulating costs would be vastly different as cancellation decisions are much more costly than registration decisions in terms of data gathering, personnel, legal hearings, etc.

Nevertheless, the benefit-cost system that is developed in this study can provide the direction for pesticide regulatory decision-making in areas other than registration and reregistration of chemical pesticides. Flexibility must be exercised, however, in applying the techniques to areas other than those intended for by the present benefit-cost system.

1.3 Methodology

The analysis begins in Chapter 2.0 by describing the biological basis for benefit-cost assessment of pesticide use. The commonly recognized pests are described, followed by the various pest control alternatives available to counteract these pests. Benefits and costs associated with various uses of pesticides are outlined, along with those entities receiving benefits or incurring costs from pesticide use. General problems associated with the measurement of benefits and costs are then touched upon. Thus, the chapter provides the basis for the creation of benefit-cost matrices and the analytic procedures that follow.

Chapter 3.0 continues with an economic-theoretic basis for the use of benefit-cost concepts in analyzing pesticide use. Benefits and costs are described as being either internal to the decision-making process or external to the decision-making process. A set of matrices are developed outlining the various benefits and costs received or incurred by the various entities in the pesticide use decision process. One matrix is presented for each pesticide use category, i.e., pesticides used in food, feed, and fiber production, pesticides used in health/disease vector and nuisance pest control, pesticides used in commercial-industrial situations, pesticides used in providing aesthetic improvement, and pesticides used in providing environmental management.

Upon examining the matrices, it becomes evident that there are market uncertainties for the pesticide producer and economic, social, and environmental uncertainties for users, consumers, and society as a whole. Therefore, it was necessary to develop a series of flexible algorithms and analytic techniques that could be used in each of the pesticide use categories, when necessary. These algorithms are referred to as "submodels" in this study, and alternative techniques for quantifying each submodel are available. All submodels pertinent to a pesticide registration decision should be used.

Hence, those segments of the benefit-cost matrices developed in Chapter 3.0 that will receive the most use during pesticide product registration decisions have been fully developed as submodels. These include the food, feed, and fiber production submodel developed in Chapter 4.0, the health effects submodel developed in Chapter 5.0, and the environmental effects submodel developed in Chapter 6.0. In each of these three chapters, procedures for calculating the relevant benefits and costs -- outlined in Appendix B and in the matrices of Chapter 3.0 -- are discussed, along with the data requirements and possible data sources. Overall, the models are intended to draw on existing public agency and research data, as well as data supplied by the registration process itself. With these data, a range of benefits and costs can be assessed which are likely to occur if a proposed pesticide is registered. For pesticides on which substantial historical and test data exist, the range can be made quite narrow, but in the case of very innovative and unknown chemical compositions, the range must be broadly defined as best it can be, by drawing on toxicity, persistence, and effectiveness data for similar materials and formulations. Furthermore, summary formats of the most prominent indicators of benefits and costs are provided, so that all benefits and costs, and especially those which are conceptually and empirically difficult to measure -- such as long-term health and indirect environmental effects -- are formatted and depicted in the most comparable presentation possible.

Chapter 7.0 completes the description of the benefit-cost system by providing a summary of the three submodels presented in Chapters 4.0, 5.0, and 6.0. In this way, the user of the methodology gets a "feel" for what the system can provide in terms of assessing benefits and costs associated with the use of a pesticide. This, in turn, allows the user to see the dimensions on which a decision concerning registration or reregistration of a pesticide product can be made.

The testing of the benefit-cost system, and in particular, the procedures developed in Chapters 4.0, 5.0, and 6.0, completes the study and is accomplished using an hypothetical phenoxy herbicide seeking registration for use on wheat, oats, and barley crops. The results of this case study appear in a separate volume.

2.0 THE BIOLOGICAL BASIS FOR BENEFIT-COST ASSESSMENT OF PESTICIDE USE

2.1 Introduction

Pesticides are used to manipulate biological components of the earth ecosystem. Public Law 92-516 defines "pest" as "(1) any insect, rodent, nematode, fungus, weed or (2) any other form of terrestrial or aquatic plant or animal life or virus, bacteria, or other micro-organism (except viruses, bacteria, or other micro-organisms on or in living man or other living animals) which the Administrator (EPA) declares to be a pest." The term pesticide in Act 92-516 is defined as "(1) any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any pest and (2) any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant."

The term pest applied to a living organism reflects a subjective decision on the part of human society as a whole, or some component of society, that a certain organism existing in a certain manner is undesirable or unwanted. Perhaps the classic instance of this human decision is that of weeds which are defined as plants out of place or in an unwanted situation.

Pesticides represent all kinds of chemical configurations and molecular arrangements, even including insect viral pathogens. The unifying thread of all pesticides is that they possess physiological activity against living organisms. The one exception to this statement is the growth regulator category. These materials rather than being toxicants or antagonists are designed to modify or change plant growth in ways deemed desirable for certain human purposes. In a legal sense, to protect public health, as well as the environment, Public Law 92-516 has placed plant growth regulators in the pesticide category even though they are not used as toxicants.

This placement presents some difficulty in the analysis of pest control and pesticide use from a theoretical biological viewpoint. By way of solution, we have included plant growth regulators in the weed control taxonomies where they seem to present little practical difficulty in benefit-cost analysis.

In its broadest sense, pest control involves all manipulations of organisms in the earth ecosystem to favor those organisms, commodities, and structures valued by man. Chemical pest control, i.e., use of substances under the regulatory purvues of 92-516, represents only a fraction of the available alternative techniques or systems that may be used in pest control. From man's first beginnings he has been seeking better, more effective ways of accomplishing these alterations in organismal ascendency.

2.2 Pest Control Alternatives

It appeared essential to the contractor that one of the first tasks to be accomplished prior to initiation of any benefit-cost procedures was to create biologically sound taxonomies of pest control alternatives so that the consequences of a registration denial or cancellation could reflect, as closely as possible, the expected results from non-use of the pesticide in question. These should be all-encompassing frameworks that would maintain their integrity well into the future and could be modified through additions if needed but hopefully would not need such modification.

Nature and natural systems represent a continuum. Man constantly categorizes and classifies nature with partitions and boxes. The sciences and technologies of pest control involve numerous academic disciplines and departments. Traditionally, these have been separate entities with little interchange. Thus, insect control, plant disease control, and weed control investigations have proceeded largely along separate lines. Substantial gaps in knowledge have existed at the interfaces of these traditional investigation areas. Indeed, in some instances the investigations have resulted in pest control systems with paradoxical effects when the individual procedures and practices are brought together on a single crop, animal, or commodity.

For benefit-cost procedures to be a truly effective means of viewing pest control alternatives, such procedures must be grounded in the best possible theoretical framework that will allow analysis of pesticide benefits and costs in the continuum of natural systems. Excerpted from nature, such procedures will accomplish nothing and may be worse than intuitive judgment in mediating pesticide registration decisions.

For example, pesticide control of a given insect may result in a 20 percent yield increase for the crop in question. However, control of the insect may allow a weed host previously insect-suppressed to compete with the crop and reduce the crop yield by 30 percent. Application of a herbicide to control the weed results in complete weed control but reduces the crop yield by 10 percent through phytotoxicity, as well as predisposing it to a plant pathogen that results in a 30 percent yield decrease unless sprayed with a fungicide for its control which will again result in optimum yield. Such examples, although seemingly rare, may well be all too common if pest control alternatives are not comprehensively examined in detail. Benefit-cost analysis, if not equally comprehensive in all respects, will also result in distortions and inaccuracies. Extended research is necessary to gain insights of this nature. Therefore, these insights may only be possible for reregistration decisions, unless information is already available for new registrations as well.

In order to provide a biologically sound framework for this analysis technique, a taxonomy of commonly recognized pests and taxonomies of pest control alternatives for the four major categories of pests are synthesized (see Appendix A). These are:

- Plant pathogens: those organisms that form a continuing relationship with plants resulting in adverse effects termed disease.
- Weeds: plants that compete with desired species for water, nutrients, and other environmental components, as well as occupy space on waters and lands deemed essential for other uses.
- Insect and other arthropods: that feed upon, antagonize, or deform plants, animals, man, commodities or structures.
- Vertebrates: that feed upon, or antagonize man and his plants, animals, and possessions.

Information used in creation of these taxonomies was obtained from numerous publications and texts, the more useful of which are cited in Section 2.7.

In viewing previous existing attempts at delineation of pest control alternatives, two problems were apparent: (1) incompleteness and omission of certain alternatives, and (2) overlapping, whereby a control method could be placed in any of several categories. Completeness is believed to have been achieved and most of the errors of omission were corrected. The problem of overlap is still unsolved and at this stage it appears insolvable except through arbitrary decision on placement of specific methods in certain cells.

Introduction of a new pesticide in most instances (at the present stage in evolution of agricultural technology) represents introduction of an alternative material for a pesticide control technique already in existence and in this sense the new introduction (i.e., registration in a regulatory sense) may: provide for greater efficacy; provide a solution to an organismal tolerance problem on the part of pre-existing materials; or merely broaden the spectrum of materials available for specific uses. In a few instances, the new material may represent a method for control of a previously insolvable pest problem and thus represent a new technique. In a few other instances, the substance may represent replacement of a previously existing non-chemical technique, e.g., crop rotation, with a new chemical technique. Other non-pesticidal reasons for introduction may be lower human and animal toxicity or lower environmental hazard in any or all areas.

Public Law 92-516 states in Sec. 2(C)(5) that the Administrator shall register a pesticide if he determines that when used as intended, it is efficacious, complies with labeling and other requirements, and will not cause "unreasonable adverse effects on the environment." In addition, in the legislative history, there appears a discussion that comparison of one pesticide with another is a "natural" in economics.* New pesticides to be registered will receive much closer scrutiny in all probability than did many older pre-existing materials. In a pragmatic sense, during registration, comparison of a new environmentally safer product with an older one having significant hazard may be impossible to avoid. Furthermore, in any cancellation or suspension proceedings, it would appear that availability of, and comparison with, suitable, safer alternative materials becomes a crucial consideration, especially with major food, feed, and fiber crops and severe pest problems.

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*U. S. House of Representatives Report No. 92-511, Ninety-second Congress, First Session, 1971, p. 14.

Hence, the benefit-cost analysis must provide a basis for comparison of the pesticide under evaluation with other existing pesticides and other means of control so that a meaningful estimate of the net contribution -- i.e., incremental benefit -- of the pesticide registration under consideration will be insured.

2.3 Benefits and Costs from Pest Control

Pesticides are used in numerous and diverse ways and for different purposes, often having little natural relationships to each other. It readily became evident that a single benefit-cost matrix could not provide a basis for analysis of all uses. Hence, to provide a theoretically sound basis, pesticide usage was divided into five categories that seem to account for all possible uses or purpose of uses, and yet each are similar enough to allow one analysis procedure for each category. These are as follows:

- Pesticide use in food, feed, and fiber production: to include such items as crop production, animal production, cotton, forest products, and all other crops and commodities including storing, processing, and consumption of these commodities.

- Pesticide use in health/disease vector and nuisance pest control: to include such items as mosquito abatement, household pests, rabies vectors, ants in lawns, caterpillars in a resort community.

- Pesticide use in commercial-industrial situations: to include utility and highway rights-of-way, oil tank farms and industrial sites, factory buildings, structural pests in wood, in commercial and home situations.

- Pesticide use in providing aesthetic improvement: to include shade trees, turfgrass, golf courses, home lawns and flowers and all vegetation where appearance is the criterion of quality measurement such as a resort landscape.

- Pesticide use in providing environmental management: to include fishery resource regulation (i.e., lamprey eel), forest pests where ecosystem balance is deemed essential, and all other uses where environmental quality and ecological considerations are the overriding basis for pesticide use.

Within each of these categories, taxonomies of entities receiving benefits and incurring costs were created from a biological-social science basis (see Appendix B). It is recognized that in each of these taxonomies, the approach is not on an economic basis. This is done in Chapter 3.0 in the creation of the matrices. Obviously, as created, the taxonomies list as many as possible of the individual entities involved in incurring costs or receiving benefits, recognizing that in may instances, the benefits or costs transfer through, accruing at various points within the taxonomy.

2.4 Measuring Benefits and Costs

One major problem in benefit-cost analysis with pesticides is the diversity of benefits and costs, especially with regard to externalities. Many of these are almost intangible in the sense that they represent feelings about future problems such as genetic damage, mutations, and ecosystem disruption, yet in the short run they may represent bases for pesticide cancellation or non-registration. Many externalities are non-quantifiable even though of a tangible nature, often because of the absence of any data or lack of reliable data. This is especially true in the realm of environmental effects. Taken as a whole, there is a tremendous mass of information dealing with environmental damage. Most is only descriptive.

For example, the Mrak Commission report (Parts I and II, HEW, December, 1969) cites numerous studies of potential environmental injury from pesticides, generally in terms of the kinds of physiologic upset induced by given levels of pesticides under laboratory conditions. Extrapolation of such data to the natural situation becomes extremely difficult, if not impossible, without confirmatory data that measures ambient pesticide levels, as well as sampling for injury in nature. In most instances, the kind of data simply does not exist that would allow one to say, for example, that DDT when used in New Brunswick for spruce budworm control resulted in an X percentage reduction in salmon reproduction and a Y percentage reduction in trout. These problems are recognized by most competent scientists working in the pesticide environment area, and world-wide experimentation is under way to quantify environmental effects where possible.

Perhaps an equally serious problem from the biological point of view is the lack of knowledge concerning internal benefits from certain kinds of pesticide use. Pesticide evaluation in terms of efficacy has traditionally been carried out in replicated small plot areas for plants and with small pens or cages for animals. Where non-mobile weeds or soil-borne insects and plant pathogens have been involved, the small plot yield response benefits from pest reduction may be representative of actual field situations. For example, the yield responses from replicated herbicide plots in a weedy corn field are likely to be indicative of the yield response from the whole field or other commercial fields of similar species and degree of weediness. This would be especially true if the experimentation were carried out utilizing the best possible experimental designs and statistical analysis procedures. Such research and data obtained are relatively straightforward and provide an excellent measure of one type of internal pesticide benefit from the herbicide use in question.

In general, chemical weed control represents the most straightforward situation in pesticide use. Herbicides and growth regulators are used against non-mobile target organisms. The universality of their occurrence allows experimentation to occur on portions of commercial fields with extrapolation to commercial results being readily possible, as well as being reasonably valid.

The situation with mobile plant pathogens and insects is not nearly as clear cut. Crop, commodity, and animal loss assessment is a severely neglected branch of most of the pest-related academic disciplines. The academic reward structure has not provided incentives for research in these areas. As a result, much of the information available represents estimates of the crudest sort with very little or no statistical basis.

This situation is belatedly being corrected. Current Smithsonian Science Information Exchange (SSIE) research project listings indicate that many new agricultural research projects have been initiated within the last year to determine economic thresholds for insect and weed infestations and disease outbreaks. In addition, research is under way involving pest loss appraisal techniques. The best information currently available worldwise has been compiled in the Food and Agriculture Organization of the United Nations (FAO/UN) Manual, "Crop Loss Assessment Methods -- Pests, Diseases and Weeds."* This manual is updated through supplements issued periodically. These methods, developed by competent researchers throughout the world, deal with single problems, i.e., one insect, or one disease, and are very useful within these constraints. The interpretive problems arise when several insects, weeds or diseases of various genera occur simultaneously on the same crop plant or animal. As mentioned previously, essentially no information exists for these complex situations. However, this problem is being recognized and hopefully research will soon be underway in various locations.

A more serious problem in pest control benefit and cost appraisal is the cryptic or representational error present in field experiments with mobile pests or pathogens. This has been recognized by a few researchers but has been documented most prominently by Van der Plank in his text, Plant Diseases: Epidemics and Control.**

A brief consideration of this problem is essential since much of the experimentation in use today in pesticide efficacy evaluation contains this interpretive error. Most pesticide field experiments consist of small plots treated with various chemical configurations and include numbers of untreated check plots. The various treatments are compared with each other, as well as with the untreated check plots. In agricultural research, the individual plots are taken to represent farmers' fields or orchards and results obtained from the plots are interpreted to bear a close relationship to what would take place under commercial conditions of use.

Various experimental designs and statistical procedures are normally employed to deal with the plot-to-plot variation and experimental error. It is an accepted principle of field plot research that test plots must not interfere with each other; thus, the intensity of pest development in one plot should not influence pest development in

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*Available from the Commonwealth Agricultural Bureau, Central Sales Branch, Farnham House, Farnham Royal, Slough SL2 3BN, England.

**Van der Plank, J. G., Plant Diseases: Epidemics and Control, New York, Academic Press, 1963.

an adjacent plot, either upward or downward. In fertilizer experiments, one or two guard rows are normally left between plots and this suffices to prevent fertilizer overlap and interference between treatment plots. In weed control plots with a pre-existing weed population and no in-season movement of seeds, this is also the case. However, when plots are established for control of insects or mobile air-borne plant pathogens, a few guard rows are meaningless and the unsprayed or untreated check plots may remain a season-long source of inoculum and spread for heavy contamination of the treatment plots. In this instance, the pesticide has a much harder task of pest suppression than in a farmer's field; hence, with protectant materials, the experimental or test pesticides are usually not as effective on a unit weight or volume basis as they would be under commercial conditions.

In past years where the insurance concept of pesticide use was prevalent and the general objective was to subject the material to the most severe conditions conceivable, such an approach might have been justifiable. However, at the present state of pesticide science and technology, this approach may result in two serious problems:

- Chemical dosage programs developed on the basis of such tests will result in overuse of chemicals at much higher than necessary rates, as well as shorter treatment intervals. This may be one of the reasons why "pest management" programs with reduced dosages have been strikingly effective.

- In relation to commercial conditions, the range in pest damage or loss between no treatment and treatment may be either too great or not great enough but seldom will there be an accurate representation of commercial expectations. The new systemic pesticides which provide complete absolute pest suppression will result in a drastic difference, especially if everything in the plots favor pest development.

Thus, excessive pesticide benefits are calculated. On the other hand, with a protectant pesticide which provides partial suppression, the difference will be much less than in a commercial field and the benefits would be calculated to be less than would actually be derived from commercial use. Neither error in the benefit calculation can be tolerated. A possible approach to alleviate this problem would be to

check and compare test data for the new pesticide with both test data and commercial field data for a parallel pesticide. This concept is further discussed below.

2.5 Evaluation of a Pesticide in Terms of Parallel Comparisons with Similar Materials

In the registration of either a new pesticide containing new active ingredients or a new formulation of an existing material, much can be learned by parallel comparison of the new pesticide with existing registered materials. Existing pesticides of long standing registration experience will often have received intensive research attention in many areas of environmental and human health concerns, particularly if there is evidence that harm has resulted. As a result of this research emphasis over a period of years, a record of the presence or absence of acute or chronic problems such as human or wildlife effects, injury to applicators, etc., will be established.

New pesticide materials of similar or related chemical configuration may present similar problems. Some of these will only become evident after long usage and research experience. From a scientific view, comparison of parallels represents one of the most viable techniques for anticipation of future problems. Such comparison may allow registration of materials for general use when at initial review the potential for hazard would seem to dictate that the product should be a restricted use registration, or such comparison may allow registration of materials for restricted use when at initial review the potential for hazard would seem to dictate that the product should not be registered at all. The technique thus can be used both to expedite, as well as to preclude or restrict registration.

Data and testing procedures for registration should be within methodology guidelines that allow meaningful comparisons between experimental results for a single chemical, as well as between chemicals. It is recognized that effective investigation requires imagination and initiative on the part of the researcher. On the other hand, diversity between experimental techniques and designs often precludes any kind of comparison between experiments. Unfortunately, much of the pesticide registrations to date have been supported by data gathered in such diverse manners.

Therefore, as a first step, listings of acceptable protocols (i.e., procedures) must be developed for as many as possible of the categories of data needed for registration. Considering the individualism existing among research scientists, standardized test protocols do not appear in the realm of possibility. Perhaps even more important, the complexity of evaluation requirements indicates that standardization would not be scientifically sound in many areas of testing.

However, listing of acceptable procedures should be completed as soon as possible by competent scientists involved in this work. Initial efforts in this area have been started by committees (E 35) formed within the American Society for Testing and Materials (ASTM) framework. However, progress to date in most areas after almost two years effort is negligible especially with regard to efficacy testing. Through its Registration Guidelines, EPA will initiate an open-ended specification of acceptable procedures. Much greater emphasis is needed in this work, especially through stimulus by the EPA, as well as the pesticide chemical industry.

If registration data are submitted through procedures and methods included under acceptable protocol guidelines of both ASTM and EPA, the benefit-cost procedure can proceed on a much sounder basis. Especially pertinent to the present discussion is the fact that parallel comparison of pesticides, to be most meaningful, should be based on data generated through similar evaluation procedures.

The data required for parallel comparison must involve all areas of pesticide evaluation, including efficacy and human and environmental hazard. The data requirements for registration as published in the Federal Register of October 16, 1974, and outlined in the following paragraphs are suggested as a basis for data needed for parallel chemical comparisons and for benefit-cost analysis.

2.5.1 Efficacy

Evidence of product efficacy is normally demonstrated through laboratory and/or field testing procedures which closely approach actual use(s). The following general data are needed:

- Minimum effective dosage and dosage range,

- Description of application techniques, including equipment used in application, method, timing, and site of application,

- Evaluation of the action of the product in preventing, destroying, repelling or mitigating a pest; accelerating or retarding the rate of growth or otherwise altering the behavior of plants; defoliating plants or artificially accelerating the drying of plant tissue, and

- Evaluation of the chemical and physical compatibilities of components of formulated pesticides, including the compatibility of mixtures of pesticides with dilutents, emulsifiers, fertilizers, solvents, spreaders, and stickers.

2.5.2 General and Environmental Chemistry

The following general data are needed:

- For all pesticide product uses,
    - Name, chemical indentity and composition of the pesticide,
    - Physical and chemical properties of both active ingredients and formulations,
    - Basic manufacturing process and purity of starting and intermediate materials,
    - Composition and methods of analysis for the principal component(s), including significant impurities in the technical material,
    - Methods of analysis for active ingredient(s) in the formulated product,
    - Storage stability of the formulated product under a relevant range of conditions,
    - Data in support of safe container disposal techniques.

- For outdoor terrestrial uses,
    - Pesticide data and movement in soil,
        - Rate, mechanisms, and degree of degradation of the parent pesticide and its degradation products,
        - Analytical procedures for separation and identification of degradation products,

        - Characterization of "bound" residues,
        - Residue data for rotational crops.
    - Soil persistence data under actual use conditions,
    - Laboratory scale leaching data on the product pesticide and the soil degradation products,
    - Laboratory scale runoff data,
    - Rate of hydrolysis.

For uses on or adjacent to aquatic sites,

- Dissipation rate of parent pesticide and important degradation products in distilled water,
- Degradation in bottom sediments and in water containing suspended solids,
- Duration of biological activity in the aquatic environment,
- Laboratory and/or field data on pesticide movement in water and uptake by aquatic plants, organisms, and crops irrigated with treated water,
- Levels of residues in milk, animal tissue and eggs, when livestock or poultry can reasonably be expected to be exposed to and/or consume treated water,
- Fish uptake and dissipation data,
- Photodegradation data on the parent pesticide,
- Rate of volatilization of the pesticide under typical conditions of use.

2.5.3 Product Hazard

Laboratory and field studies: When data on active ingredient(s) and formulation do not allow a satisfactory decision on product hazard, further studies are needed for major metabolites, degradates and/or reaction products.

- Human effects,
    - Acute effects data including oral, dermal, inhalation, and ocular exposure hazard,
    - Subacute, chronic, and delayed effects data including potential mutagenic, teratogenic, oncogenic, metabolic or other chronic effects hazards,

  - Safety data including diagnostic and antidotal information, and precautions necessary for reentry into treated areas.

- Environmental effects,

  - Data on the hazard to fish and wildlife including mammalian toxicity, acute and subacute avian toxicity, acute aquatic organism toxicity, and subacute, delayed or chronic effects hazards.

Comparison of the foregoing types of data for a new pesticide product with existing registrations should provide a good basis for selecting a parallel pesticide with similar characteristics as the new pesticide product. This will, in turn, provide additional insights about a new pesticide, normally only available for pesticides presently or previously registered. It is recognized that satisfying data needs for a new pesticide by using information about its parallel may produce biased results. Nevertheless, a good basis for estimations in a benefit-cost analysis can be achieved. Protocols for data presentation should be such that the data are amenable to benefit-cost procedures without excessive transformation.

2.6 Summary

Benefit-cost analysis is no better than the data available for use as inputs into the analysis. Data without validity, reliability or relevance produces results that are worthless if not completely misleading.

In this chapter, taxonomies of pest control alternatives, pesticide use categories, and benefits and costs have been created. These have a sound biological and rational basis and support creation of benefit-cost matrices and analytical procedures.

It must be remembered, however, that the data presently available on pesticides benefits and costs are limited and subject to bias, as well as inaccurate assumptions. The results obtained must be viewed in this light. However, the analytic procedures should be nonetheless valid and of even greater significance in the future as better information becomes available to work with.

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3.0 THE ECONOMIC EVALUATION OF THE BENEFITS AND COSTS OF PESTICIDE USE

3.1 Introduction

For theoretical clarity in the development of the biological basis for benefit-cost assessment of pesticide use, Chapter 2.0 has established distinctions between five categories of pesticide use. These distinctions are extremely useful in producing descriptions of the effects arising from the manufacture, distribution, and application of pesticides in each of these five use categories. However, the general similarity of the types of effects which are sustained by each entity which receives benefits or incurs costs across all of these categories would make the presentation of a detailed description of the economic evaluation of each effect in each use category superfluous.

The analysis which is developed in this chapter first demonstrates that the total net benefit which accrues to society as a result of the adoption of a new pesticide can be evaluated most easily if it is decomposed into the net internal benefit and the net external benefit which are generated by this adoption. The net internal benefit is then theoretically proven to be equal to the sum of the change in consumers' surplus obtained by users of the final products which are treated with the new pesticide, the increase in monopoly profits which are earned by the producers and distributors of both the pesticide and the products which are treated with the pesticide, and the change in economic rent realized by owners of fixed inputs throughout the nation. However, practical consideration of the quantification problems and the relative empirical significance of these component benefits and costs leads to the conclusion that this net internal benefit should be estimated solely as the change in consumers' surplus attributable to the adoption of the new pesticide.

In a similar manner, the analysis next establishes theoretically that the net external benefit is equal to the net total of the health and environmental costs and benefits which accrue to households and public agencies and the monitoring and regulating costs which are borne by public agencies. Suggested techniques for estimating the magnitudes of these individual benefits and costs are then described.

Finally, a specification, in matrix form of the relationship of these economic evaluations to the five pesticide use categories is presented.

3.2 Evaluation of Benefits and Costs

In describing techniques for the measurement of benefits and costs, it is convenient to distinguish between net internal benefits and net external benefits. Net internal benefits are the net total of benefits and costs which are incurred voluntarily by decision-making entities and whose values are determined through prices and markets; while net external benefits are the net total of benefits and costs which accrue involuntarily to members of society other than the decision-making entity and whose values are not reflected in the price of the product. Obviously, these net benefits may be positive or negative. To calculate these net benefit measures correctly, caution must be exercised to eliminate any pecuniary effects which might be present in the individual benefit and cost measures prior to aggregating these individual measures.

3.2.1 Net Internal Benefits

To estimate the net internal benefits attributable to a new pesticide, it is necessary to consider both the competitive situation in the industry which will use the pesticide and the role to be performed by the new pesticide. For example, for a pesticide used in food, feed, and fiber production, the role could be (1) a new use which increases yield and thus reduces cost per unit; (2) a new use which increases the quality of the product and thus increases price per unit; or (3) a new use which replaces other, more expensive, factors of production (including the replacement of an existing pesticide with a less costly one) and, thus, reduces cost per unit. Of course, a new pesticide might perform a combination of these roles. It might be a cheaper replacement for an existing pesticide and produce a higher yield than could be obtained with that pesticide. In this case, care must be taken to include all benefits and costs associated with each role.

Since more definitive conclusions about the measurement of net internal benefit can be derived for the use of a new pesticide by a perfectly competitive industry than for its use by an oligopolistic industry, the perfectly competitive case will be discussed first. Moreover, this discussion will begin with the consideration of a pesticide which performs a cost-reducing role.

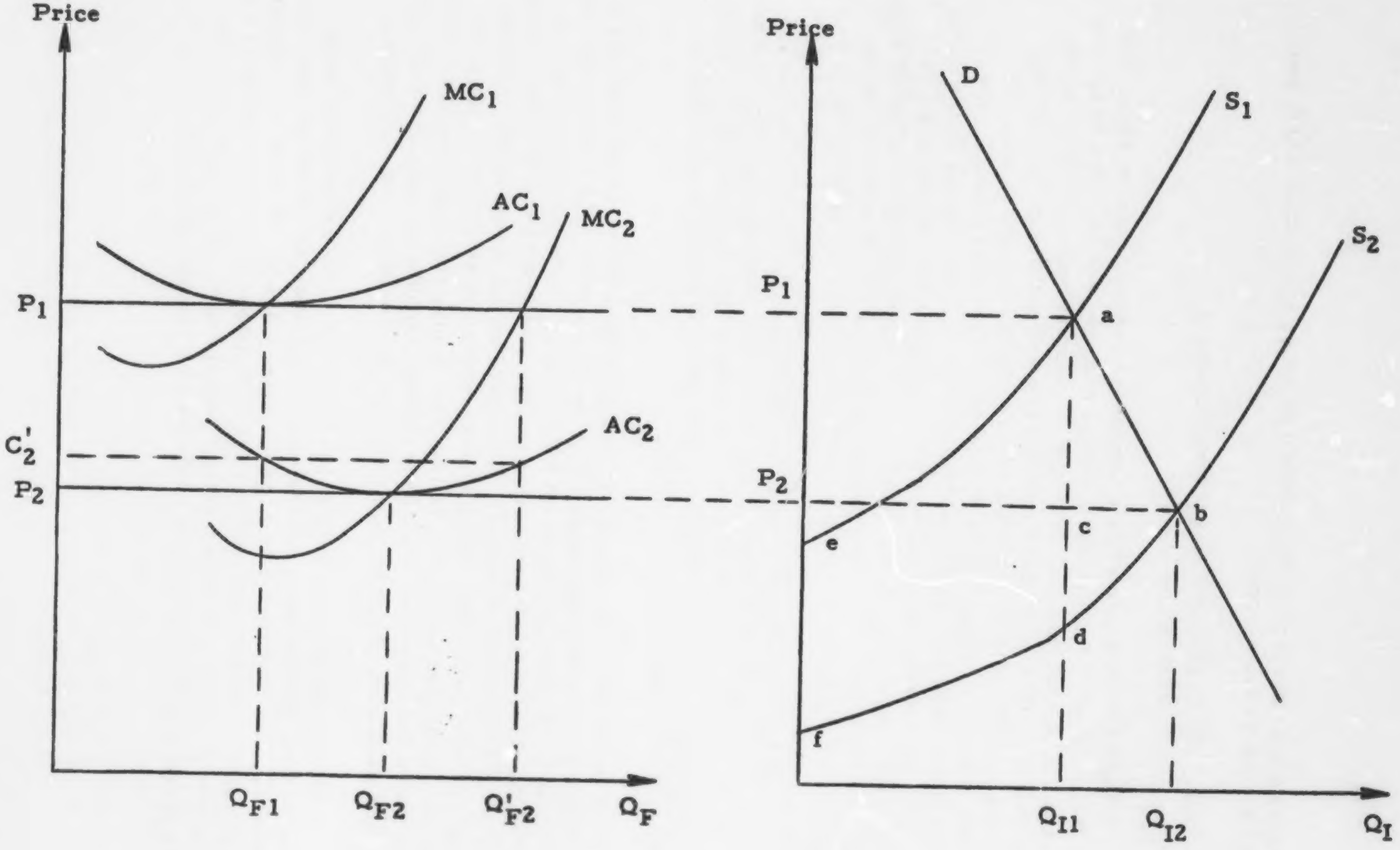
3.2.1.1 Perfectly Competitive Industry: Cost-Reducing Use

Producers in a perfectly competitive industry cannot retain for very long any increased profit arising from the use of a new pesticide which reduces cost per unit of output. Industry supply will increase in response to this new profit opportunity and market price will fall until pure profit returns to zero. Thus, in this situation, the net internal benefit of using a new pesticide can be determined by measuring the change in consumers' surplus (i.e., the change in the value received by consumers in excess of the amount which they have paid for the final product). This conclusion is demonstrated in Exhibit 3.1, where the behavior of a representative firm in the industry is illustrated in the diagram on the left, while the behavior of the industry as a whole is illustrated in the diagram on the right. The representative firm is initially at long-run equilibrium, where it produces the quantity Q_{F1} and sells this output at the price P_1. Simultaneously, demand for the product of the industry is D and the supply function of the industry -- the horizontal summation of the marginal cost curves (the MC_1's) of all firms in the industry -- is S_1.

Now, a new pesticide which reduces the cost per unit of output is introduced. The average cost curve declines from AC_1 to AC_2 and the marginal cost curve shifts from MC_1 to MC_2. The first users of the pesticide will increase production to Q'_{F2} and initially will earn a profit of $(P_1 - C'_2)$ per unit of output. However, as all firms in the industry adopt the new pesticide, the industry supply function will increase to S_2 and the market price will fall to P_2. Thus, the representative firm returns to the zero-profit position where it produces Q_{F2} units of output and each unit of production receives its "normal" rate of return.

The preceding analysis represents the simplest possible case and, hence, innumerable extensions of this analysis could be developed. However, the vast majority of these extensions would have only minor implications for the estimation of the net internal benefits attributable to a new pesticide. Consequently, only three of these extensions which are particularly important for this estimation will be developed here.

EXHIBIT 3.1


Price
MC$_1$
AC$_1$
MC$_2$
AC$_2$
P$_1$
C$_2'$
P$_2$
Q$_{F1}$
Q$_{F2}$
Q$'_{F2}$
Q$_F$
Price
D
S$_1$
S$_2$
P$_1$
P$_2$
a
b
c
d
e
f
Q$_{I1}$
Q$_{I2}$
Q$_I$

First, not all firms in a perfectly competitive industry have identical cost functions. Thus, the availability of a new pesticide will offer different initial profit opportunities to different firms within the industry. Nevertheless, there is a tendency for the minimum average cost of all firms in the industry to converge as time passes. Less efficient firms are forced to become more efficient or to go out of business; while firms with more efficient resources (e.g., better land) find that the prices of these resources are bid up until there is no competitive advantage to using these resources instead of the best alternative resources.

Second, the preceding analysis also ignores processing and distribution costs. That is, the demand and supply curves employed in this analysis are the curves which prevail in the market where the producer sells his product; while the change in consumers' surplus which must be measured is the change in consumers' surplus which prevails in the market for the final product. Yet, the processing and distribution costs per unit of output should not change merely as a result of the introduction and use of the new pesticide. Therefore, supply, demand, and price in the retail market can be represented by shifting all points in Exhibit 3.1 upward by the amount of processing and distribution costs. This adjustment has no effect upon the measured value of the change in consumers' surplus. However, an exception to this conclusion will arise if the use of a pesticide at the farm level produces contamination or health costs which are borne by the processor or distributor. These costs will reduce consumers' surplus and will be treated later in this chapter.

The third extension of the preceding analysis involves the case where only a portion of the producers of a particular product can benefit from a new pesticide. For example, suppose that a new herbicide increases cotton yields in the Delta but produces no benefit in Western production areas. The introduction and use of this herbicide will have a depressing effect upon the price of cotton. Moreover, this price decrease initially will be associated with the earning of pure economic profits in the Delta and the incurring of economic losses in the Western areas. However, these profits and losses should be rapidly capitalized into fixed input values. Thus, it is expected that Western producers will incur capital losses (i.e., reduced land prices) while Delta farmers will enjoy capital gains. Similarly, cotton production will fall in the West and increase in the Delta.

Ideally, the net total of all changes in the values of fixed inputs which are generated by the adoption of a new pesticide -- the net change in economic rent in the nation arising from the use of that pesticide -- should be calculated and included as a component of the net internal benefit attributable to the introduction and use of the pesticide. Unfortunately, the precise amount of change in production and economic rent will depend upon the relative profitability of the alternative uses of those fixed inputs whose values in their present uses have decreased and, hence, cannot be estimated without a fairly detailed model describing the interrelationships in the entire agricultural economy. Consequently, the empirical difficulties associated with the measurement of the changes in economic rent throughout the nation precludes the inclusion of this component of net internal benefit into the benefit-cost methodology. Perhaps the best that can be done is to hope that these effects are at least partially offsetting from the aggregate standpoint. Nevertheless, some attempt should be made to identify the relative impact of the introduction and use of a new pesticide. Will one area gain relative to another? Will producers of one size gain relative to other producers? Will users of one method of production gain relative to producers using an alternative method?

Despite all of these qualifications, the primary conclusion remains that the measurement of the net internal benefits of the use of a new cost-reducing pesticide in a perfectly competitive industry must begin with the measurement of the increase in consumers' surplus generated by this innovation. The gain in consumers' surplus is represented in Exhibit 3.1 by the area P_2P_1ab. To measure this area most easily, it is desirable to divide this total area into two components: the rectangular area P_2P_1ac and the triangular area abc. Then, the rectangular area can be measured as the product of the change in price caused by the adoption of the new pesticide and the initial equilibrium output level; the triangular area can be approximated by one-half of the product of this change in price and the change in output associated with this price change; and the total change in consumers' surplus can be estimated as the sum of these two components. Detailed techniques for calculating the change in price and the change in output attributable to the adoption of a new pesticide are developed in Chapter 4.0.

With the exception of the monopoly profits obtained by the producer of the pesticide as a result of his patent, this measurement of consumers' surplus will capture the net effect of all internal benefits and costs which arise from the use of the new pesticide. This consumers' surplus is derived from the reduced price of the product and constitutes a net gain after the subtraction of all internal costs, including:

- The cost of the pesticide to the producer of the final product. If the decision of the pesticide manufacturer to produce this pesticide is economically rational, this cost must include:
  - The cost of management, labor, capital, and materials used in producing and marketing the pesticide, and
  - The proportion of the total contamination, environmental, and health costs which are borne by the manufacturer.
- The cost of application of the pesticide, including:
  - The cost of management, labor, capital, and materials (other than the pesticide) used in application, and
  - The portion of the total contamination, environmental, and health costs which are borne by the applicator.
- The net long-run gain (equals zero in perfect competition) to producers of the final product. This gain will include:
  - Changes in the costs of management, labor, capital, and materials used in production, and
  - The proportion of the total contamination, environmental, and health costs which are borne by the producer.
- The contamination, environmental, and health costs which are borne by firms further down the processor-distributor chain.

It is important to recognize that ideally the internal costs which are incorporated into the measurement of the change in consumers' surplus which is attributable to the use of a new pesticide should not include the costs associated with the research and development of that pesticide. By the time that a manufacturer submits an application for the registration of a pesticide to the EPA, all of these research and development costs already have been incurred. More importantly, it is impossible at this time for the manufacturer to avoid incurring or to recover these costs by selling or diverting to other uses those resources whose utilization generated these costs. Therefore, since these costs must be incurred by the manufacturer -- and by society -- regardless of the outcome of the registration decision, the inclusion of these costs in the calculations which determine the outcome of this decision would be inappropriate and could produce an economically inefficient allocation of resources. If the registration process refuses to permit the marketing of a pesticide whose benefits exceed all costs associated with the manufacture and use of that pesticide except its research and development costs, society would be denied a net benefit equal to the difference between the benefits of the pesticide and its non-research and development costs. Moreover, this net benefit could be used to partially defray the unavoidable research and development costs and, thereby, to offset to some extent the loss which has been imposed upon the manufacturer and society for this relatively unproductive research and development effort.

Clearly, this same rationale is applicable to any other element of cost which has been incurred and is irrecoverable when the registration procedure is initiated. Consequently, the production cost data which is incorporated in the benefit-cost analysis of a pesticide should include only those cost elements which are avoidable if registration is denied. Specifically, no data concerning the research and development costs of creating a new pesticide should be collected unless these data are required to eliminate this cost element from a more aggregative set of cost data.

3.2.1.2 Perfectly Competitive Industry: Price-Increasing Use

A new pesticide which increases the quality of a product produced by a perfectly competitive industry will, in the long run, cause an increase in price equal to the increase in cost per unit which is attributable to the use of the pesticide. Early adopters of the pesticide once again will earn a pure economic profit. However, as more producers adopt the pesticide, competition will cause the price to fall until economic profits return to zero. Thus, once again, the entire net internal benefit is passed on to the consumers in the form of consumers' surplus, which in this case consists of the added-value of the higher quality product less the additional costs which have been required to attain this increase in quality. This change in consumers' surplus can be estimated in the same manner as the change in consumers' surplus which is attributable to the use of a new pesticide which reduces cost per unit of output. Moreover, all of the qualifications and assumptions which have been expressed for a cost-reducing use apply equally well to a price-increasing use.

3.2.1.3 Oligopolistic Industry

If any of the firms which are involved in the production, processing, distribution, or use of either the new pesticide or products whose production processes utilize the new pesticide are members of oligopolistic industries, the preceding analysis must be qualified slightly. Since oligopolistic industries have at least some control over price, not all of the net internal benefits will be passed on to the consumers. The firms may be able to retain a portion of these benefits as pure economic profits. In addition, these net internal benefits may be slightly smaller than they would have been if all relevant industries were perfectly competitive.

However, if there are at least several firms in each of these relevant industries, these effects should be small and, hence, can be reasonably ignored. Therefore, the net internal benefits associated with the use of a new pesticide in an oligopolistic situation will be estimated, using essentially the same techniques which have been developed for the measurement of consumers' surplus in the perfectly competitive situation. However, in the oligopolistic situation, the division of these net internal benefits between producers and consumers will not be determined, since the computation of the proportions of these benefits which accrue to producers and consumers would require detailed knowledge of the competitive structure of each relevant industry.

3.2.1.4 Measurement of Net Internal Benefits

To summarize the conclusions of the preceding analysis, the net internal benefits attributable to the introduction and use of a new pesticide have been determined to be equal to the sum of (1) the monopoly profits which accrue to the pesticide producer as a result of his patent, (2) the net change in economic rent realized by owners of fixed inputs throughout the nation, and (3) the consumers' surplus obtained by users in competitive industries or (3') the consumers' surplus obtained by users plus the pure economic profits obtained by producers in oligopolistic industries. Moreover, items (3) and (3') in this summation are estimated using identical procedures.

Although the direct measurement of the four items -- to the extent that they can be measured -- constitutes sufficient input into the calculation of net internal benefits for the purpose of evaluating the aggregate economic justifiability of the introduction of a new pesticide, it is frequently desirable to obtain some indication of the distribution of these aggregate net benefits among the various entities whose individual benefits and costs comprise this sum. In particular, one indication of these distributional effects can be obtained by evaluating the following accounting equation:

$$\begin{aligned} NIB = {} & MP + A\,(\Delta Y \cdot P + \Delta P \cdot Y + 1/2 \cdot \Delta P \cdot \Delta Y - \Delta F) \\ & - A\,(P_p + C_p) - H_a - H_b \end{aligned}$$

where: NIB = net internal benefits,

MP = the pure economic profit received by the producer of the pesticide as a result of his patent,

A = number of production units (acres of land, head of livestock, yards of cloth, etc.) to which the new pesticide is applied,

Y = yield of the final product per unit used to measure A,

ΔY = change in yield of the final product attributable to the use of the new pesticide,

P = price of the final product,

ΔP = change in price of the final product attributable to improved quantity and/or quality of the product resulting from the use of the new pesticide,

ΔF = value per unit used to measure A of the change in productive input requirements resulting from the use of the new pesticide,

P_p = price of the new pesticide per unit used to measure A (i.e., cost of the new pesticide per acre, per head, etc.),

C_p = cost of applying the new pesticide per unit used to measure A,

H_a = net contamination, environmental, and health costs borne by the user of the pesticide, and

H_b = net contamination, environmental, and health costs borne by firms further down the producer-consumer chain than the user of the pesticide.

Observe that the net change in economic rent in the nation, ΔER, defined as the net change in the portion of total payments to resources which does not influence the amount of those resources available for utilization, is embodied within this accounting equation in the terms:

$$\Delta ER = A \cdot \Delta Y \cdot P - A \cdot \Delta F - A\,(P_p + C_p) - H_a - H_b$$

Consequently, it is possible to provide a graphical representation of virtually all of the basic accounting equation within the context of Exhibit 3.1. Specifically, the expression $(A \cdot \Delta P \cdot Y)$ is depicted by the area P_2P_1ac; the expression $(A \cdot 1/2 \cdot \Delta P \cdot \Delta Y)$ is described by the area abc; the expression $(A \cdot P \cdot \Delta Y)$ is illustrated by the area $Q_{I1}Q_{I2}bc$; the expression $[A \cdot \Delta F + A\,(P_p + C_p) + H_a + H_b]$ is represented by the area $Q_{I1}Q_{I2}bd$; and, hence, ΔER is approximated by the area bcd.* Only the term MP cannot readily be portrayed within the context of this exhibit.

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*To be perfectly rigorous, the net change in economic rent should be measured as that portion of the difference between areas P_2bf and P_1ae which does not constitute a pure pecuniary change in payments to variable resources (i.e., a net change in the portion of total payments to resources which does influence the amount of those resources

Finally, the procedures which can be used to estimate the values of each of the terms within this accounting equation are:

MP - When the firm which holds the patent for the new pesticide licenses another firm to manufacture and sell the pesticide, the amount paid by the licensee can be used to estimate the value of the patent. Alternatively, this value can be estimated by comparing the rates of return to capital in the pesticide-producing industries to rates of return in similar manufacturing industries which do not have patent protection for their products and processes. Clearly, the implementation of either of these estimation techniques would require extensive data acquisition and manipulation. Moreover, the magnitude of these monopoly profits are extremely likely to be substantially smaller than the change in consumers' surplus attributable to the introduction of a new pesticide. Consequently, it is recommended that no concentrated efforts should be devoted to the estimation of these monopoly profits. MP may be zero or positive.

A - Estimate the number of production units (acres, head, etc.) which are afflicted by relevant pests and multiply this number by a factor which reflects the probable proportion of these production units which will be treated with the new pesticide. This proportion can be estimated from past experience with similar pesticides used on similar pests.

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available for utilization). Clearly, this quantity cannot be identified unambiguously in Exhibit 3.1, although it can be reasonably represented by the area bcd. For a thorough economic analysis of this issue, see either E. J. Mishan, "What Is Producer's Surplus," American Economic Review, Vol. 58, December, 1968, pp. 1269-1282 or E. J. Mishan, Cost-Benefit Analysis, Praeger Publishers, Inc., New York, 1971, pp. 48-56.

Y - Obtain yield estimates from published statistics.

ΔY - Obtain estimates of the change in yield from experimental trials which test the effectiveness of the new pesticide. Caution must be exercised to guarantee that results are used only from experimental trials in which conditions are similar to those found on the premises of potential users of the pesticide. ΔY can be positive, zero or negative.

P - Obtain price estimates from published statistics or from projections made by the Department of Agriculture or other public agencies.

ΔP - Estimate this change in price from quantity and/or quality price differentials which are observed in current markets. ΔP can be positive, zero or negative (i.e., use of the new pesticide may increase, not change or decrease the average quantity and/or quality and, hence, the average price of the product).

ΔF - Estimate this input substitution effect from experimental trials which test the effectiveness of the new pesticide. These changes in input cost include changes in capital, labor, and material costs, in addition to cost of formerly used pesticides which have been replaced by the new pesticide. ΔF can be zero or negative, but is unlikely to be positive.

P_p - Estimates of the cost of the new pesticide must be obtained from the pesticide manufacturer. This cost is the product of the manufacturer's proposed selling price at the retail level and the recommended application rate per unit used to measure A.

C_p - Estimate application costs using published data on charges for custom application. It is important to recognize that these charges will simultaneously measure the contamination, environmental, and health costs which are associated with application to the extent that these charges are sufficiently high to compensate for insurance premiums and lost time attributable to pesticide-induced illness.

H_a - These contamination, environmental, and health costs include the cost of additional liability and health insurance, production losses caused by illnesses attributable to the new pesticide, medical bills paid by the user, and output destroyed by contamination. Quantities of probable losses can be estimated from published studies of losses attributable to similar pesticides. H_a can be negative, zero or positive. A negative H_a would be obtained if the new pesticide replaces one which has greater contamination, environmental, and health costs to the user.

H_b - These costs can be measured in the same manner as H_a.

3.2.1.5 The Desirability of Marginal Production Cost Data

The attainment of economic efficiency requires that the marginal benefit obtained by society from the use of a pesticide must be equated to the marginal cost incurred by society from the use of that pesticide. However, since the registration process makes a separate decision on the introduction and use of each individual formulation which contains a particular active ingredient rather than making a single decision on the introduction and use of the active ingredient itself, the satisfaction of this economic efficiency condition may be difficult to guarantee through the registration process. For example, if a new formulation containing a particular active ingredient is proposed for registration and if the approval of this registration will result in an increase in the total quantity of this active ingredient which is introduced into the environment (i.e., if this new formulation does not merely displace an equivalent amount of presently registered formulations which contain this active ingredient), the marginal cost incurred by society from the use of this active ingredient will increase. If the utilization of this active ingredient has been economically efficient prior to the proposal for registration of the new formulation, the attainment of economic efficiency subsequent to the approval of this proposal will require not only that the marginal benefit obtained by society from the use of this new formulation must be equated to this new level of marginal social cost, but also that the marginal benefit obtained by society from the use of each presently registered formulation which contains this active ingredient must be increased until it becomes equal to this new level of marginal social cost. Thus, in general, the utilization rate of each presently registered formulation must be reduced until this new efficiency condition is attained.

The specification of the precise nature of this adjustment requires the simultaneous consideration of the registration of all formulations which contain a particular active ingredient. Thus, whenever a new formulation which contains a particular active ingredient is proposed for registration, the registration of all presently registered formulations which contain this active ingredient must be reconsidered. Yet, while this requirement is deceptively simple to express as a concept, it clearly is very likely to be extremely difficult to satisfy in practice. The quantity of information which must be accumulated and analyzed is prodigious. Moreover, even if this analysis were to be performed, the existing Federal legislation does not grant to the EPA sufficient authority to enforce the implementation of the policies which would be recommended on the basis of the analysis. Although this legislation authorizes the promulgation of regulations which specify the application rate and the pre-harvest application interval of a formulation, it does not permit the regulation of the total quantity of the formulation which is applied or, equivalently, the total acreage upon which the formulation may be applied. Consequently, in terms of the applicability of the analysis, the simultaneous consideration of all formulations which contain a particular active ingredient would be an unproductive exercise, since the results of this extensive analysis would be impossible to implement in detail. Therefore, recognizing both the difficulty of performing this extended analysis and the limited possibility of implementing the results of this analysis, it appears reasonable to restrict the benefit-cost methodology to the evaluation of each individual formulation independently and, subsequently, to compare the independently derived evaluations of all alternative formulations which can be applied to the same use to determine the optimal registration pattern.

Nevertheless, within each of these independently derived evaluations, it remains desirable to obtain and utilize data which reflects the marginal cost of producing the formulation which is being evaluated. Unfortunately, the published data on pesticide manufacturing costs do not provide this degree of detail; the potential usefulness of information of this type as a basis for industry price fixing or output rationing has motivated the Antitrust Division of the Justice Department to enjoin industry trade associations from assembling and distributing these data; and the competitive structure of the pesticide industry makes it extremely unwise for any pesticide manufacturer or formulator to divulge this information voluntarily to anyone external to his firm. Thus, in performing the case studies, it undoubtedly will be necessary to rely on average production cost data as inputs into the benefit-cost methodology. Once again, ideally, these average cost data will reflect production costs net of the cost of research and development and all other cost elements which have been incurred and are irrecoverable when the registration process is utilized.

Utilizing these average cost data as if they were marginal cost data within the benefit-cost methodology is tantamount to assuming that the pesticide industry is a constant-cost industry -- that the average cost curve of the industry is a horizontal line instead of a U-shaped curve. However, this assumption is not inconsistent with the empirical results derived in numerous statistical studies of production costs for relatively high levels of output* and, hence, does not appear to be unreasonable in the present context.

3.2.2 Net External Benefits

Many of the costs and benefits attributable to the use of a new pesticide will not be reflected in the costs incurred by firms and the prices prevailing in markets. These external costs and benefits include the health and environmental benefits and costs which accrue to households and public agencies and the monitoring and regulating costs which are borne by public agencies. Extreme caution must be exercised to avoid double-counting when estimating the value of these external effects. To illustrate the potential severity of this problem, two examples will be discussed.

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*See, for example, J. Johnston, Statistical Cost Analysis, New York, McGraw-Hill Book Company, 1960.

First, consider a case in which a pesticide manufacturer has an accidental spill of his pesticide which kills fish in a stream. A government agency replaces these fish and the manufacturer is required by the courts to reimburse the agency. Since the manufacturer has made this payment, this cost is an internal cost which will be reflected in the price which is charged for the pesticide. Thus, it is inappropriate to include the cost as an environmental cost which is borne by a public agency.

Similarly, consider a migrant worker who becomes ill as a result of long-term exposure to pesticides. He is unable to work, becomes eligible for public assistance, and has his medical bills paid by a public agency. The health costs which are borne by the public agency include the medical bills plus his support payments. In addition, there is an income loss which is borne by the household of the disabled worker. However, this income loss is not equal to the wages that the worker has lost. Rather, the income loss is equal to the difference between these lost wages and the support payments. To include both the total lost wages and the support payments as health costs would constitute double-counting.

Recognizing this potential for errors of measurement, approaches to the evaluation of the external benefits and costs which are attributable to the production and use of a new pesticide are discussed in the remainder of this section.

3.2.2.1 Health Benefits and Costs Accruing to Households

The incidence of adverse health effects can be estimated from experiences with similar pesticides in the past. The total health cost borne by households is equal to the sum of medical costs, lost earnings due to illness or death, and damages for pain and suffering, which might be estimated by studying court awards in appropriate cases. Positive health effects could result from a reduction in the adverse effects of competitive pesticides which are replaced by the new pesticide. The same techniques which have been proposed to measure health costs can be employed to measure these health effects. These techniques will be described in greater detail later in this report.

3.2.2.2 Health Benefits and Costs Accruing to Public Agencies

The health costs which are borne by public agencies primarily consist of the costs of the public assistance which is provided to sick and disabled workers and their families. The incidence of adverse health effects can be estimated from experiences with similar pesticides in the past; while the costs of public assistance can be estimated from the budgets of relevant public agencies. Furthermore, adverse health effects to public agency employees applying pesticides must be included to the extent they are borne by the public agencies.

In addition to these direct costs, the health costs which are borne by public agencies should include any incremental expenditures on research into pesticide-related illnesses which are attributable to the registration and use of the new pesticide. However, these research costs may be extremely difficult to estimate with any reasonable degree of accuracy and may have to be ignored. Any health benefits which are obtained by public agencies will result from a reduction in the adverse health effects of competitive pesticides which are replaced by the new pesticide and can be measured in the same manner as health costs will be estimated.

3.2.2.3 Environmental Benefits and Costs Accruing to Households

The most likely form of environmental damage which might be associated with the use of a new pesticide is damage to non-target species. The incidence of these damages can be estimated from experiences with similar pesticides in the past. These damages can constitute economic losses, aesthetic losses, or both. Economic losses can be evaluated, using market prices or replacement costs. Reversible aesthetic losses can be evaluated as the cost of restoration or replacement. Finally, irreversible aesthetic losses can be partially evaluated by reference to studies which impute from people's observed behavior the minimum amount of income which they would have been willing to surrender to enjoy particular aesthetic experiences. However, to completely evaluate these irreversible aesthetic losses, it is necessary to determine the maximum amount of income which people would be willing to surrender to enjoy these aesthetic experiences.

Consequently, the available imputation techniques fail to measure a substantial portion (i.e., the difference between the maximum and minimum amounts of income) of the consumers' surplus obtained from these aesthetic experiences. Moreover, because an individual's honest revelation of the maximum amount of income that he would be willing to pay for a good or service can be used as a basis for charging him for his consumption of that good or service, it is theoretically impossible to obtain accurate estimates of irreversible aesthetic losses using direct surveying techniques. Thus, if the available imputation techniques are determined to be inadequate, it probably will be necessary to rely on the Delphi approach to estimate irreversible aesthetic losses.

Environmental benefits will arise from the use of a new pesticide through the reduction of the environmental costs which are attributable to alternative pesticides. These benefits can be evaluated by utilizing the same techniques which have been described for the measurement of environmental costs.

3.2.2.4 Environmental Benefits and Costs Accruing to Public Agencies

The environmental costs which are borne by public agencies consist of the costs which have been incurred by the public sector to correct the environmental damages which result from the use of the new pesticide. The incidence of these damages can be estimated from past experiences with similar pesticides; while the costs of correction of these damages can be estimated from the budgets of relevant public agencies. Similarly, any environmental benefits which are produced by the reduced use of alternative pesticides can be estimated in this same manner.

3.2.2.5 Regulatory Benefits and Costs Accruing to Public Agencies

The regulatory costs which are borne by public agencies include all costs associated with the registration or cancellation of the new pesticide which are expected to be incurred after the initial decision to register the pesticide has been taken; the costs of monitoring the impacts of the use of the new pesticide which are borne by the EPA and other public agencies; any incremental governmental support for research into the prevention, detection, control, and correction of pesticide-related contamination, environmental, and health damages which is attributable to the use of the new pesticide; and the cost of any incremental government-supported research into the effectiveness and proper use of pesticides which is undertaken as a result of the introduction and use of the new pesticide. To the extent that these cost elements can be isolated, their magnitudes can be estimated from the budgets of the relevant public agencies.

However, the two cost elements which are related to governmental support for research may be extremely difficult to isolate with any reasonable degree of accuracy and may have to be ignored. Any regulatory benefits which result from the reduced use of alternative pesticides can be evaluated in the same manner, using the same data sources. Finally, the cost of any additional monitoring of pesticide use and damage which might be performed by private individuals or agencies can be imputed from the cost experiences of the public agencies.

3.2.3 The Treatment of the Displacement of Competitive Pesticides

The registration and subsequent production of any new pesticide is likely to cause a decrease in the sales of other presently registered pesticides and, consequently, a decrease in the utilization of the inputs which are used in the production of these other pesticides. However, if the economy is reasonably competitive (i.e., if the prices which are paid for these inputs reasonably reflect the opportunity cost of using these inputs) and if the economy is reasonably near to full employment, this displacement of inputs will comprise merely a transfer of these inputs from utilization in the production of the other pesticides to utilization in their best alternative employment opportunities. Consequently, the payments to these inputs should not be considered in the benefit-cost evaluation of the new pesticide. In fact, a consideration of these payments might lead to an inappropriate decision to refuse registration of a socially beneficial new pesticide.

Yet, if the registration and subsequent production of the new pesticide will cause a change in the nature or extent of the hazards which are borne by society, this effect should be considered in the benefit-cost evaluation of the new pesticide. Specifically, the results of the benefit-cost evaluation of the new pesticide should be compared to the results of the benefit-cost evaluation of all presently registered pesticides which can be applied to any of the uses for which the new pesticide is proposed and, ideally, on the basis of this comparison, decisions should be taken on both the registration of the new pesticide and the cancellation of some alternative pesticides.

3.2.4 Discounting Future Benefits and Costs

Obviously, it is extremely unlikely that all of the benefits and costs attributable to the adoption of a new pesticide will accrue to society at the same point in time. Consequently, since present benefits of a particular dollar amount are more valuable than future benefits of the same dollar amount, at least to the extent that the monetary equivalent of the present benefits can be invested at a positive rate of return to yield greater wealth in the future, it is necessary to discount future benefits and costs to make them commensurable with present values.

While the need for this conversion is generally accepted, there has been substantial controversy about the appropriate discount rate to employ in performing this conversion. The essence of this controversy can be appreciated by considering the two most prominent positions which have been advocated in this debate.

On the one hand, most market-oriented economists have agreed that the appropriate discount rate to apply to a public investment is the opportunity cost of the resources which will be utilized in that investment as measured by the rate of return which these resources will earn if they are employed in their best alternative private use.* However, acceptance of this proposed resolution of the controversy introduces the serious practical problem of determining this rate of return. Theoretically, the appropriate discount rate for a particular governmental project consists of a weighted average of the different rates of return which will be earned in private sectors from which the resources to implement this project will be withdrawn. Unfortunately, in practice, these private rates of return cannot be observed directly; and the data series on corporate profits from which they must be estimated are generally poor.

Conversely, some economists have contended that requiring public investments to earn rates of return which are at least equal to the rates of return which are earned by equivalent investments in the private sector will produce an inadequate level of public investment. Consequently, they contend that a discount rate which is lower than the

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*See, for example, William J. Baumol, "On the Discount Rate for Public Expenditures," in *The Analysis and Evaluation of Price Expenditures: The PPB System, Vol. 1*, Washington, U. S. Government Printing Office, 1969, pp. 489-503.

opportunity cost of capital should be applied to governmental projects.* For this policy to be economically justifiable, it must be true that these governmental projects produce external economies which cause their social rate of return to exceed the prevailing private rate of return. Although this assertion might be valid for some public projects, it would be incorrect to assume that this deviation between social and private rates of return would exist -- and, indeed, exist to the same extent -- for all governmental investments. Moreover, the isolation and evaluation of externalities of this type frequently constitutes the primary purpose for performing a benefit-cost analysis. Thus, assuming the existence of these externalities by employing an artificially low discount rate in a benefit-cost analysis may be essentially equivalent to the double-counting of external benefits and inevitably will introduce a bias into the analysis which favors the implementation of socially undesirable public projects.

Although a complete resolution of this controversy concerning the appropriate social discount rate has not yet been attained, it is clear that extreme caution should be exercised to insure the theoretical validity of any benefit-cost analysis in which an artificially low discount rate is employed to evaluate public projects. Consequently, in general, it is recommended that the discount rate which is employed in benefit-cost analysis should reflect the opportunity cost of the resources which will be utilized in the project under consideration and, hence, should constitute an estimate of the expected real pre-tax rate of return on private investment. This recommendation is supported by the Office of Management and Budget, which estimates "the average rate of return on private investment, before taxes and after inflation," to be 10 percent and requires the use of this discount rate in the evaluation of the majority of the programs and projects which it oversees.**

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*See, for example, Steven A. Marglin, "The Social Rate of Discount and the Optimal Rate of Investment," Quarterly Journal of Economics, February, 1963, pp. 95-112.

**Office of Management and Budget, "Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits," Circular No. A-94, Revised, March 27, 1972.

3.2.5 The Economic Benefits and Costs Associated with Each Category of Pesticide Use

Exhibits 3.2 through 3.6 on the following five pages relate the economic measures of benefits and costs which have been discussed in the present chapter to the five categories of pesticide use which have been defined in Chapter 2.0. Thus, these exhibits contain a specification of the distribution of the major types of benefits and costs which are attributable to the introduction and use of a new pesticide. This distribution is defined with respect to both the entities which receive benefits or incur the costs and the use category for which the application of the pesticide is intended.

Furthermore, the benefits and costs described in the matrices may be either quantifiable in dollar terms (i.e., representable by a monetary value derived using actual market prices), quantifiable in non-dollar terms (i.e., representable by, at most, an incidence rate, a probability and/or a number of people, birds, fish, etc., receiving benefits and/or incurring damages of a certain type), or intangible (i.e., representable by only a qualitative statement concerning the type and nature of benefits received and/or damages incurred by a selected entity).

EXHIBIT 3.2: Pesticides Used in Food, Feed, and Fiber Production

Entity Which Receives Benefits or Incurs Costs	Benefits			Costs		
	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible
Supplier (Manufacturer, Distributor, Commercial Applicator*)	Change in revenue attributable to sale of pesticide (short-run and long-run)			Change in costs of production, distribution, etc. Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Business/Industrial User	Reduced cost of inputs for food processors and clothing manufacturers Increased revenues from additional sale of processed food and clothing			Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Agriculture/Forestry User	Increased profits (attributable to change in revenues and change in costs of inputs other than new pesticide) caused by increased crop yield			Change in cost of pesticides Change in costs of application Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Household User	Value of increased food and clothing production (including improved nutrition) Reduction of adverse health effects (attributable to competitive pesticides) borne by households			Cost of increased food and clothing production Portion of costs of change of adverse health effects of new pesticides borne by households Damage to non-target species		
Public Agency User	Change in productivity of research performed by agriculture departments of universities			Portion of costs of change of adverse health effects borne by agencies		

*If an analysis of the distribution of benefits and costs among these three entities is determined to be desirable, a separate row can be established for each type of supplier.

EXHIBIT 3.3: Pesticides Used in Health/Disease Vector and Nuisance Pest Control

	Benefits			Costs		
Entity Which Receives Benefits or Incurs Costs	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible
Supplier (Manufacturer, Distributor, Commercial Applicator*)	Change in revenue attributable to sale of pesticide (short-run and long-run)			Change in costs of production, distribution, etc. Increased production costs due to contamination of inputs by residuals Portion of cost of change of adverse health effects borne by employer		
Business/Industrial User	Reduced cost of inputs other than new pesticide (especially labor) Increased revenues from sale of additional output			Change in cost of pesticides Change in cost of application Increased production costs due to contamination of inputs by residuals Portion of cost of change of adverse health effects borne by employer		
Agriculture/Forestry User	Increased profits (attributable to change in revenues and change in costs of inputs other than new pesticide)			Change in cost of pesticides Change in cost of application Increased production costs due to contamination of inputs by residuals Portion of cost of change of adverse health effects borne by employer		
Household User	Value of increased output of goods Beneficial health effects arising from reduction of disease Improved aesthetic quality of household arising from reduction of health/disease vector			Change in cost of pesticides Change in cost of application Cost of increased output of goods Portion of costs of change of unintended adverse health effects borne by households Damage to non-target species Damage caused by misapplication by households		
Public Agency User				Change in cost of pesticides Change in cost of application Portion of costs of change of adverse health effects borne by agencies		

*If an analysis of the distribution of benefits and costs among these three estimates is determined to be desirable, a separate row can be established for each type of supplier.

EXHIBIT 3.4: Pesticides Used in Providing Aesthetic Improvement

	Benefits			Costs		
Entity Which Receives Benefits or Incurs Costs	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible
Supplier (Manufacturer, Distributor, Commercial Applicator*)	Change in revenue attributable to sale of pesticide (short-run and long-run)			Change in costs of production, distribution, etc. Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Business/Industrial User	Reduced cost of labor input due to improved working conditions Increased profits due to improved public image Increased revenues from sale of additional output			Change in cost of pesticides Change in cost of application Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Agriculture/Forestry User	Increased profits (attributable to change in revenues from sale of additional output and change in cost of inputs)			Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Household User	Value of increased output of goods Increase in property value attributable to aesthetic improvements Value of aesthetic improvements to public Surplus value of aesthetic improvements to owner			Change in cost of pesticides Change in cost of application Cost of increased output of goods Portion of costs of change of adverse health effects borne by households Damage to non-target species Damage caused by misapplication by households		
Public Agency User	Increased revenue of marketed public recreation areas Increased usage of free public recreation areas			Change in cost of pesticides Change in cost of application Portion of costs of change of adverse health effects borne by agencies Change in cost of other inputs of public recreation areas		

*If an analysis of the distribution of benefits and costs among these three entities is determined to be desirable, a separate row can be established for each type of supplier.

EXHIBIT 3.5: Pesticides Used in Providing Environmental Management

Entity Which Receives Benefits or Incurs Costs	Benefits			Costs		
	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible
Supplier (Manufacturer, Distributor, Commercial Applicator*)	Change in revenue attributable to sale of pesticide (short-run and long-run)			Change in costs of production, distribution, etc. Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employers		
Business/Industrial User	Increase in revenue of private recreation and tourism areas Decreased production costs due to improvement of quality of inputs Increased revenues from sale of additional output			Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Agriculture/Forestry User	Decreased production costs due to improvement in quality of inputs Increased revenue from sale of additional output			Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Household User	Value of increased output of goods Value of aesthetic improvement of environment Beneficial health effects due to environmental improvement			Cost of increased output of goods Portion of costs of change of adverse health effects borne by households Damage to non-target species		
Public Agency User	Increased revenue of marketed public recreation areas Increased usage of free public recreation areas			Change in cost of pesticides Change in cost of application Portion of costs of change of adverse health effects borne by agencies Change in cost of other inputs of public recreation areas		

*If an analysis of the distribution of benefits and costs among these three entities is determined to be desirable, a separate row can be established for each type of supplier.

EXHIBIT 3.6: Pesticides Used in Commercial/Industrial Situations

Entity Which Receives Benefits or Incurs Costs	Benefits			Costs		
	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible	Quantifiable in Dollar Terms	Quantifiable in Non-Dollar Terms	Intangible
Supplier (Manufacturer, Distributor, Commercial Applicator*)	Change in revenue attributable to sale of pesticide (short-run and long-run)			Change in costs of production, distribution, etc. Increased production costs due to contamination of inputs by residuals Portion of cost of change of adverse health effects borne by employer		
Business/Industrial User	Increased profits (attributable to change in revenues and change in costs of inputs other than new pesticide)			Change in cost of pesticides Change in cost of application Increased production costs due to contamination of inputs by residuals Portion of cost of change of adverse health effects borne by employer		
Agriculture/Forestry User	Increased profits (attributable to change in revenues from sale of additional output and change in cost of inputs)			Increased production costs due to contamination of inputs by residuals Portion of costs of change of adverse health effects borne by employer		
Household User	Value of increased output of goods Reduction of adverse health effects (attributable to competitive pesticides) borne by households			Cost of increased output of goods Portion of costs of change of adverse health effects borne by households Damage to non-target species		
Public Agency User				Portion of costs of change of adverse health effects borne by agencies		

*If an analysis of the distribution of benefits and costs among these three estimates is determined to be desirable, a separate row can be established for each type of supplier.

3.3 Structure of the Benefit-Cost Submodels

The preceding discussion describes the economic assumptions and basic concepts for analyzing benefits and costs of pesticides. These assumptions and concepts are grounded in the conventional economics of industrial production. Thus, the pesticide process is envisioned to occur in numerous firms of varying size, each of which has its own capital/output factor and its own financial structure. Each firm may engage in some research and new product development activities and some level of competition is ensured because of Federal antitrust regulations.

Each firm faces many uncertainties as it brings its pesticide products to the market place, one of which is the Federal registration process. Without passing this barrier, the pesticide product will not even be allowed into the market. Once inside the market, the pesticide product may have to compete for users' dollars with other pesticides for each type of use. The increased crop yield is one factor which may help to ensure a successful competitive career for a pesticide, and the pesticide manufacturer will strive to establish competitive prices which will generate adequate returns for his effective products.

These prices become the costs for the agricultural or other pest control user. The benefits of higher yield become benefits for everyone who consumes the crop, but the costs of health and environmental damages may impinge on some people and not on others, depending on how these effects are engendered.

These uncertainties, including the market uncertainties for the pesticide producer and the social and environmental cost uncertainties for users, consumers, and society as a whole, have demanded a series of flexible algorithms and analytic techniques for use by OPP. These algorithms are referred to below as "submodels," and alternative techniques for quantifying each submodel are available. All submodels pertinent to a pesticide registration decision should be used. Therefore, those segments of the benefit-cost matrix shown above that will receive the most use during pesticide product registration decisions have been fully developed as submodels and include the food, feed, and fiber production, health effects, and environmental effects submodels.*

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*A pesticide manufacturing submodel could also be fully developed, if desired, based upon the discussion in this chapter.

The structure of these models is described in the remainder of this report.

Overall, the models are intended to draw on existing public agency and research data, as well as data supplied by the registration process itself. With these data, a range of benefits and costs can be assessed which are likely to occur if a proposed pesticide is registered. For pesticides on which substantial historical and test data exist, the range can be made quite narrow, but in the case of very innovative and unknown chemical compositions, the range must be broadly defined as best it can be, by drawing on toxicity, persistence, and effectiveness data for similar materials and formulations.

4.0 THE FOOD, FEED, AND FIBER PRODUCTION SUBMODEL

4.1 Background

The problem of assessing the likely benefits and costs of pesticide use requires the making of some assumptions concerning the manner in which the pesticide will be used. Although the information required for the registration of a new pesticide provides much information on toxicity, it is likely that some assumptions will be necessary to permit the estimation of the total number of acres to which the pesticide will be applied and, subsequently, the total amount of the pesticide which will be applied.

This problem is further complicated by the possible changes which can occur after registration is granted, such as changes in price or changes in application techniques and costs. Consequently, to devise a broadly useful benefit-cost system, it is essential to provide guidelines for making assumptions concerning the manner in which a new pesticide will be used.

4.2 Net Benefits to Society from Pesticide Use

As shown in the preceding benefit-cost matrices, the major categories of benefits attributable to pesticide use are: increased food, feed, and fiber production; reduction of health/disease vectors and nuisance pests; enhancement of commercial-industrial situations; aesthetic improvement; and environmental management. The food, feed, and fiber production category is defined to include both crops and livestock, and covers crops grown for livestock consumption (feed), and non-food crops such as cotton and flax. Other benefits in plant production include growth of trees for wood, ornamental shrubs and flowers, and special product plants.

The concept of benefits from use of chemicals on these plants assumes that the growing environment can be improved in at least three ways:

- Removing harmful animals from the plant environment, mainly insects,

- Removing other plants which compete for nutrients and sunlight; these other plants are usually called weeds, and

- Changing the plant structure itself, usually by a chemical called a growth regulator, thus, the size and foliage of a plant are loosely included as part of its own environment.

Fungicides are a major category of pesticides which are used both in the field and on harvested crops to prevent fungus growth during storage. However, instead of making a separate category, fungicides can be included in either of the first two categories above. The intention of all of these uses, regardless of category, is to improve the health of the crop plants so that the actual yield is protected or increased.

The analysis presented in Chapter 3.0 has generated the conclusion that the value of the net internal benefit attributable to an increase in yield is appropriately measured by the sum of the changes in consumers' surplus, economic rent, and monopoly profits which are produced by this yield increase. Moreover, this analysis also has demonstrated that the changes in economic rent and monopoly profits are likely to be both extremely difficult to estimate empirically and, more importantly, small in magnitude relative to the change in consumers' surplus. Consequently, the analysis asserts that the net internal benefit attributable to an increase in yield can be reasonably and appropriately approximated by this change in consumers' surplus, which can be estimated as:

$$\Delta CS_{ijt} = \Delta P_{ijt} \cdot Q_{j,t-1} + 1/2 \cdot \Delta P_{ijt} \cdot \Delta Q_{ijt}$$

where: ΔCS_{ijt} = the estimated change in consumers' surplus attributable to the application of pesticide i to crop j in year t,

ΔP_{ijt} = the change in the price of crop j attributable to the application of pesticide i in year t,

$Q_{j,t-1}$ = the total output of crop j in year (t-1), and

ΔQ_{ijt} = the change in the total output of crop j in the nation attributable to the application of pesticide i in year t.

This relationship is illustrated graphically in Exhibit 4.1, where S_{t-1} represents the supply function of the industry in year (t-1), S_t represents the supply function of the industry in year t, and D represents the demand function confronting the industry in both years. In this diagram, the area $P_{jt}\ P_{j,t-1}$ ac corresponds to the expression $\Delta P_{ijt} \cdot Q_{j,t-1}$; the area abc corresponds to the expression $1/2 \cdot \Delta P_{ijt} \cdot \Delta Q_{ijt}$; and, hence, the sum of these two areas -- the area $P_{jt}\ P_{j,t-1}$ ab -- corresponds to ΔCS_{ijt}, the increase in consumers' surplus associated with the increase in supply from S_{t-1} to S_t.

To calculate ΔCS_{ijt}, it is necessary to obtain data which specify the values of ΔP_{ijt}, $Q_{j,t-1}$, and ΔQ_{ijt}. Although forecasts of $Q_{j,t-1}$ either are directly available or can be estimated relatively easily from readily accessible sources,* the calculation of ΔP_{ijt} and ΔQ_{ijt} requires substantial data manipulation. In particular, before it is possible to estimate the change in the price and total output of a crop which will result from the use of a pesticide, it is necessary to determine both the total number of acres of the crop to which the pesticide will be applied and the change in the output of that crop per acre which will result from the use of that pesticide.

4.2.1 Acres of Crops Treated by Pesticides

The number of acres of any particular crop which are treated with a pesticide varies with the observations of infestation by the farmer and with his hopes and expectations of a good yield. Yet, to assess accurately the benefits likely to be obtained from the use of

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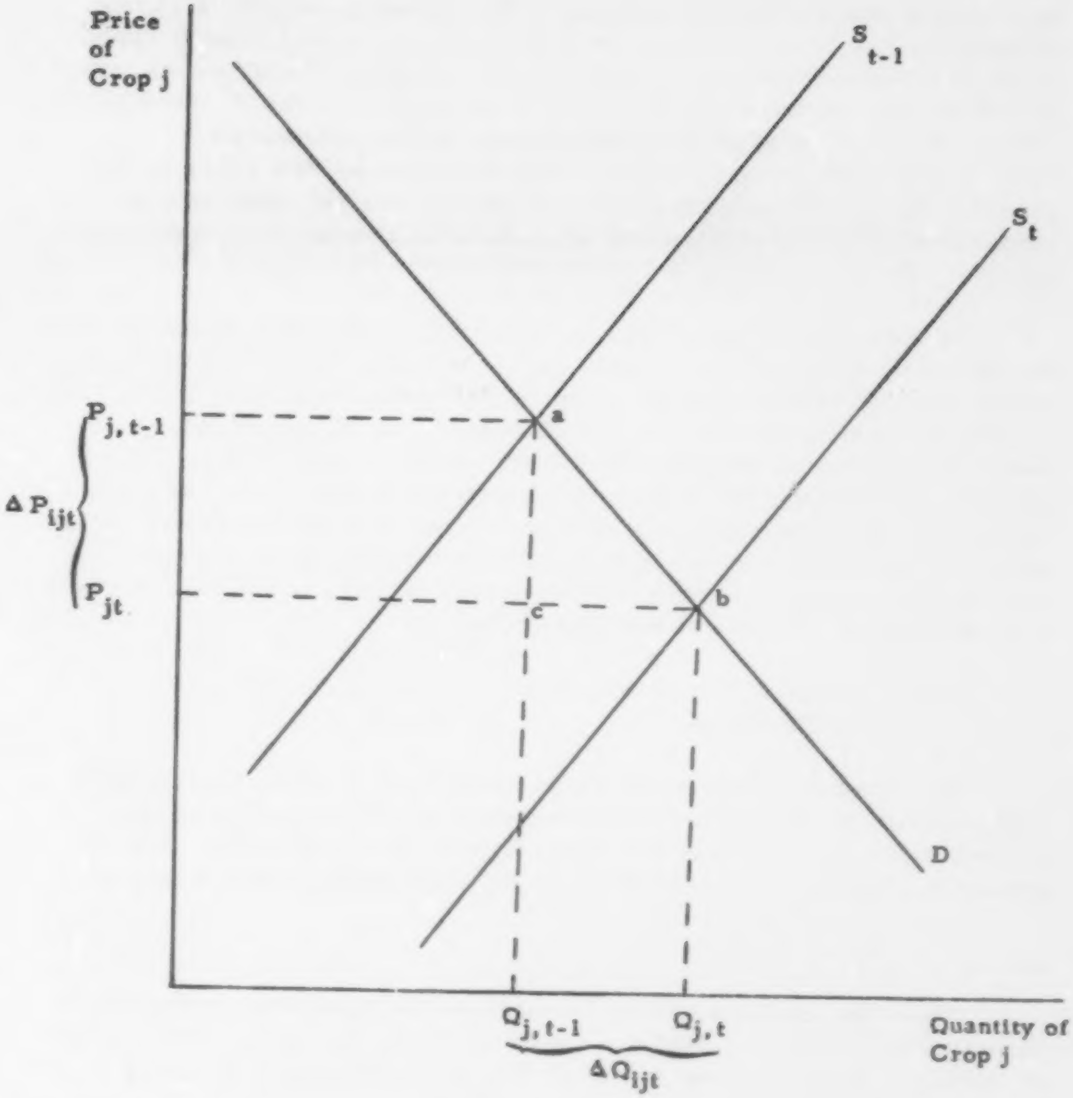
*See, for example, U.S. Department of Agriculture, Economic Research Service, National Economic Analysis Division, "Projections of the U. S. Farm Subsector and Policy Implications," Working Materials No. LQ.4.74, September, 1974.

EXHIBIT 4. 1


Price of Crop j
S_{t-1}
S_t
$P_{j,t-1}$
a
ΔP_{ijt}
P_{jt}
c
b
D
$Q_{j,t-1}$
$Q_{j,t}$
ΔQ_{ijt}
Quantity of Crop j

any proposed new pesticide, and the amount of the pesticide which is likely to be discharged into the environment, the benefit-cost system requires a procedure for calculating and forecasting the amount of the pesticide which will be applied to a specific crop in each region or state. To perform these calculations, two important data sources must be employed: the Census of Agriculture, published by the U. S. Bureau of the Census, and the survey conducted by USDA on farmers' use of pesticides. Although these sources do not always agree in totals, proportions from one source can be transferred to the other source.

Specifically, although data definitions are not always comparable between any two Censuses of Agriculture, it is possible to identify similar data categories and, hence, to calculate both the total number of acres of crops of all types to which insecticides have been applied and the total number of acres of crops of all types to which herbicides have been applied. Moreover, these data are available not only for the entire nation, but also for each state and each county. Thus, it is possible to calculate these total acreages for each of the ten agricultural regions utilized in the USDA surveys. Obtaining this degree of comparability is important because the data on pesticide use in the censuses are not available for either each specific crop or for each specific pesticide. Consequently, it is necessary, although not especially desirable, to rely upon proportional allocating factors to distribute the total acres of crops treated by insecticides or herbicides among specific crops treated by specific pesticides.

These proportional allocating factors can be calculated using the data contained in the USDA survey by employing the following equation:

$$FC_j = TCA_j/TA$$

where: FC_j = the proportion of the total number of acres in the nation to which insecticides (herbicides) have been applied which constitute acres of crop j during the survey year,

TCA_j = the total number of acres of crop j in the nation to which insecticides (herbicides) have been applied during the survey year, and

TA = the total number of acres of crops of all types in the nation to which insecticides (herbicides) have been applied during the survey year.

Applying these proportional allocating factors to the data which have been derived from the Censuses of Agriculture produces the following result:

$$TCA_{jkt} = FC_j \cdot TA_{kt}$$

where: TCA_{jkt} = the total number of acres of crop j in region k to which insecticides (herbicides) have been applied in year t,

FC_j = the proportion of the total number of acres in the nation to which insecticides (herbicides) have been applied which constitute acres of crop j during the survey year, and

TA_{kt} = the total number of acres of crops of all types in region k to which insecticides (herbicides) have been applied in year t.

If the particular use for which the new pesticide is being proposed for registration requires greater detail concerning the type of crop than can be obtained in this manner, additional disaggregation can be performed by using data on acres harvested which are available in the annual issues of Agricultural Statistics.* In particular, the issue for 1968 specifies the acreage harvested in 1966 for each of the specific crops contained in the more aggregative crop categories described in the USDA pesticide survey of 1966. This information can be employed to calculate:

$$FC'_{mj} = HA_j / THA_m$$

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*USDA, Agricultural Statistics, 1968, Washington, D.C., Superintendent of Documents, 1969, Yearbook Statistical Committee, pp. 156-233.

where: FC'_{mj} = the proportion of the total number of acres of crop category m which have been harvested which constitutes acres of specific crop j,

HA_j = the total number of acres of specific crop j which have been harvested, and

THA_m = the total number of acres of crop category m which have been harvested.

Applying these proportional allocating factors to the previously derived estimates of the total number of acres of the aggregate crop category to which insecticides or herbicides have been applied yields:

$$TCA_{jkt} = FC'_{mj} \cdot TCA_{mjt}$$

where: TCA_{jkt} = the total number of acres of crop j in region k to which insecticides (herbicides) have been applied in year t,

FC'_{mj} = the proportion of the total number of acres of crop category m which have been harvested which constitutes acres of specific crop j, and

TCA_{mjt} = the total number of acres of crop category m to which insecticides (herbicides) have been applied in year t.

It is now necessary to estimate the proportion of these TCA_{jkt} acres to which the proposed new pesticide will be applied. Fortunately, the USDA pesticide survey also provides data which permit the calculation of the following proportional allocating factors:

$$FPC_{ij} = TCPA_{ij}/TCA_j$$

where: FPC_{ij} = the proportion of the total number of acres of crop j in the nation to which insecticides (herbicides) have been applied which constitute acres to which pesticide i has been applied in the survey year,

$TCPA_{ij}$ = the total number of acres of crop j in the nation to which pesticide i has been applied in the survey year, and

TCA_j = the total number of acres of crop j in the nation to which insecticides (herbicides) have been applied during the survey year.

Moreover, given expectations about the extent to which the proposed new pesticide will displace each of the presently registered pesticides which currently are applied to a crop, it is possible to derive the following aggregative proportional allocating factor:

$$\overline{FPC_{ijt}} = \sum_m (FPC_{mj} \cdot FD_{ijmt})$$

where: $\overline{FPC_{ijt}}$ = the proportion of the total number of acres of crop j in the nation to which pesticide i will be applied in year t,

FPC_{mj} = the proportion of the total number of acres of crop j in the nation to which insecticides (herbicides) have been applied which constitutes acres to which pesticide m has been applied in the survey year, and

FD_{ijmt} = the proportion of the total number of acres of crop j in the nation to which pesticide m is applied in the base year and pesticide i is expected to be applied in year t.

In forming expectations about the displacement of presently registered pesticides by proposed new pesticides, it is suggested that, if the proposed new pesticide constitutes a substantially more efficacious or less expensive method of controlling the target pest than does the presently registered pesticide, FD_{ijmt} should be set close to (or equal to) one; while, if the proposed new pesticide constitutes a substantially less efficacious or more expensive method of controlling the target pest than does the presently registered pesticide, FD_{ijmt} should be set close to (or equal to) zero. In a similar fashion, if the pesticide under consideration is a pesticide which is being considered for reregistration, it might be reasonable to set FD_{ijmt} equal to zero for all $m \neq i$ and to set FD_{ijit} equal to one (i.e., to set $\overline{FPC_{ijt}}$ equal to FPC_{ij}). However, these suggestions should not be applied mechanically. Rather, it is advisable that the values which are assigned to FD_{ijmt} should be adjusted to reflect such considerations as the rate at which the proposed new pesticide will gain acceptance by pesticide users and the rate at which the pest population develops resistance to both the proposed new pesticide and currently registered pesticides. Obviously, adjustments of this type are more justifiable for pesticides which are confronting their initial registration action.*

Finally, the number of acres of any particular crop to which any specific pesticide will be applied in each region in each year can be estimated as:

$$TCPA_{ijkt} = \overline{FPC_{ijt}} \cdot TCA_{jkt}$$

where: $TCPA_{ijkt}$ = the estimated number of acres of crop j to which pesticide i will be applied in region k in year t,

$\overline{FPC_{ijt}}$ = the proportion of the total number of acres of crop j in the nation to which pesticide i will be applied in year t, and

TCA_{jkt} = the total number of acres of crop j in region k to which insecticides (herbicides) have been applied in year t.

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*With respect to a new pesticide, it is unrealistic to expect that all farmers who can increase their profits by adopting a new pesticide will recognize this profit opportunity and adopt the pesticide during the first year in which it is available. Rather, each farmer will decide to adopt the new pesticide at that point in time when he becomes convinced that the pesticide will generate an increase in his profits and this point in time will not be identical for all farmers. Consequently, the estimates of FD_{ijmt} which are employed in the evaluation of any new pesticide should reflect a lagged adjustment process in which the full market potential of the pesticide is realized only after the passage of a considerable period of time. A variety of statistical techniques (e.g., Koyck transformations and Almon lags) are available for the estimation of the appropriate adjustment process.

4.2.2 Change in Crop Output Attributable to Pesticides

The testing of the efficacy of pesticides in field-like situations is typically conducted on test farms which are operated by experiment stations and other agencies in all parts of the country. These experiment stations design test plot experiments in which selected plots are treated with alternative pesticides, and the results are compared on the basis of one or more measures of the effectiveness of each of the pesticides. Typical measures of effectiveness range from the numbers of insects which are observed on the plants to the actual weight of the crop yield. Some measures, such as the amount of sugar in sugar beets or the actual weight of peanut kernels, are relatively difficult to obtain; and, unfortunately, these measures do not appear often in the professional reports of these test plot experiments.

More commonly, the results are reported as percentages of decreased or increased damage from pests. These percentages may refer to some basic number of damaged fruit, ears of corn, potatoes, or other unit of yield, but the actual data on changes in damage from pests expressed in units of weight per acre are often omitted. If these changes were consistently reported in physical units, it would be relatively simple to calculate the difference which is observed between the yield which is obtained when the proposed new pesticide is applied to a crop and the yield which is obtained when no pesticides are applied to that crop.* This difference then can be applied to the previously

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*It is suggested strongly that this particular comparison is the most appropriate comparison for the pesticide registration process. Any other criterion for comparison would be substantially more difficult to standardize across different test plot experiments to the extent that it would require both the selection of a particular pesticide and the specification of a particular application rate of that pesticide as the basis for that criterion. Moreover, even with no application of pesticides as the basis for comparison, it is possible to compare the relative effectiveness of any two alternative pesticides merely by calculating the differences between each of the various indicators in their individual evaluations. Yet, it must be cautioned that if these comparisons are to be valid, it is imperative that the evaluation of each pesticide must be continually updated as additional evidence of the effects of the application of that pesticide becomes available.

estimated number of acres of the crop to which the pesticide has been applied in the region to calculate the change in crop output which is expected to be generated by the use of the pesticide. Specifically, the following equation can be evaluated:

$$\Delta Q_{ijkt} = \Delta Y_{ijkt} \cdot TCPA_{ijkt}$$

where: ΔQ_{ijkt} = the change in the total output of crop j in region k attributable to the application of pesticide i in year t,

ΔY_{ijkt} = the change in the yield per acre of crop j in region k attributable to the application of pesticide i in year t, and

$TCPA_{ijkt}$ = the estimated number of acres of crop j to which pesticide i will be applied in region k in year t.

If only percentage changes in yield per acre are reported in the experimental results, the unit of measurement for these percentage changes in yield must be converted to units of weight per acre by combining the percentage changes with data specifying the yield of the crop per acre for the state and the year in which the experiment was conducted. In general, these data on yield per acre are also reported in the experimental results. Thus, in situations of this type, the change in total output of a crop which is attributable to the application of a particular pesticide can be estimated in the following manner:

$$\Delta Q_{ijkt} = (\Delta Y/Y)_{ijkt} \cdot Y_{jkt} \cdot TCPA_{ijkt}$$

where: ΔQ_{ijkt} = the change in the total output of crop j in region k attributable to pesticide i in year t,

$(\Delta Y/Y)_{ijkt}$ = the percentage change in yield per acre of crop j in region k attributable to the application of pesticide i in year t,

Y_{jkt} = the reported yield per acre of crop j in region k in year t, and

$TCPA_{ijkt}$ = the estimated number of acres in crop j to which pesticide i will be applied in region k in year t.

These estimated regional changes in output can then be aggregated to produce an estimate of the national change in output attributable to the use of the pesticide:

$$\Delta Q_{ijt} = \sum_{k} \Delta Q_{ijkt}$$

where: ΔQ_{ijt} = the change in the total output of crop j in the nation attributable to the application of pesticide i in year t, and

ΔQ_{ijkt} = the change in the total output of crop j in region k attributable to pesticide i in year t.

4.2.3 Change in Crop Prices Attributable to Pesticides

Before the benefit which is generated by this increase in national output can be calculated, it is necessary to estimate the effect that this change in output will have upon the price of the crop. Since this increase in output is produced by an increase in the supply of the product, the effect upon the price of the crop will be determined by the demand for the crop. More specifically, the reduction in the price of the crop which is caused by this increase in output is determined by the price elasticity of demand for the crop. This price elasticity of demand is defined as:

$$E_j = (\Delta Q_j / Q_j) / (\Delta P_j / P_j)$$

where: E_j = the price elasticity of demand for crop j,

ΔQ_j = the change in the quantity demanded of crop j induced by a change in the price of crop j,

Q_j = the quantity demanded of crop j,

ΔP_j = the change in the price of crop j, and

P_j = the price of crop j.

By rearranging terms in this expression, it is possible to determine the change in price which will be associated with any particular change in quantity demanded relative to this demand function. Specifically:

$$\Delta P_j = (P_j \cdot \Delta Q_j)/(Q_j \cdot E_j)$$

or, expressing this relationship in terms of the variables associated with the use of a pesticide:

$$\Delta P_{ijt} = (P_{j,t-1} \cdot \Delta Q_{ijt})/(Q_{j,t-1} \cdot E_j)$$

where: ΔP_{ijt} = the change in the price of crop j attributable to the application of pesticide i in year t,

$P_{j,t-1}$ = the price of crop j in year (t-1),

ΔQ_{ijt} = the change in the total output of crop j in the nation attributable to application of pesticide i in year t,

$Q_{j,t-1}$ = the total output of crop j in year (t-1), and

E_j = the price elasticity of demand for crop j.

To evaluate this expression, two data elements -- $P_{j,t-1}$ and E_j -- whose sources have not yet been specified in this report must be obtained.

Many sources of data on farm crop prices are available, and these different sources are understandably confusing. For example, data from *Agricultural Statistics, 1973*, shows a slight decline in the price of peanuts from 1965 to 1966, but the same source in a separate table shows an increase in the price of oil-bearing crops of about ten percent during the same one-year interval.* Although these two data sets are admittedly measures of different variables, i.e., "peanuts,"

***Agricultural Statistics, 1973*, *op. cit.*, p. 122, Table 174, shows the decrease, and p. 459, Table 663, shows the increase.

and "oil-bearing crops," this divergence shows the danger of using a broad crop category price to estimate trends in the price of a specific crop. One important feature of the data sources mentioned is their historical time series. In addition, the Annual Price Summary* gives annual data for 20-year periods, and data for even longer periods can be compiled by using successive volumes of this series of documents. These long-term data would provide the basis for the development of a crop price forecasting model, but few such models have actually been widely used. The preliminary results from such a modeling study are shown in Projections of the U.S. Farm Subsector and Policy Implications.**

The data reported in Projections . . . , however, are not for specific crops, nor are they for specific states. Both of these levels of detail would be desirable for EPA to have in a benefit-cost system for the analysis of proposed new pesticides, since it is necessary to use data at these levels of detail when assessing possible health and environmental damages. Therefore, it is recommended that the historical data contained in the annual issues of Agricultural Statistics and the Annual Price Summary should be integrated with the aggregate price forecasts contained in Projections . . . to produce long-term crop category price indices. The rationale underlying this recommendation is that in assessing crop prices to be utilized in the determination of the benefits accruing to society from changes in crop yields attributable to pesticides, the benefit-cost system will be more conveniently usable if indices of this type are readily available and capable of direct integration into the system matrix.

Recent estimates of the price elasticity of demand for agricultural crops appears in Consumer Demand for Food Commodities in the U. S., with Projections to 1980.*** Moreover, two relatively dated

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*USDA, Agricultural Prices Annual Summary, 1973, Washington, D.C., Superintendent of Documents, June, 1974, Statistical Reporting Service, Crop Reporting Board, Pr 1-3 (74), p. 6.

**Smith, Allen, et al., Projections of the U.S. Farm Subsector and Policy Implications, USDA, Washington, D.C., September, 1974, Table 19, p. 45, Economic Projections and Analytical Systems, Economic Research Service, Working Materials No. LQ.4.74.

***George, P.S. and G. A. King, Consumer Demand for Food Commodities in the U.S., with Projections to 1980, Giannini Foundation, Monograph Number 26, March, 1971.

studies* are available which provide empirical estimates of the price elasticity of demand for a reasonably wide variety of crops. Although these studies are likely to be somewhat inaccurate to the extent that they fail to reflect the substantial increase in agricultural prices which has occurred since 1973, the general consistency with which they estimate the price elasticities of demand for agricultural crops to lie between 0.5 and 1.0 suggests that the use of their empirical estimates of elasticities in the benefit-cost system is reasonably justifiable until more current estimates become available.

4.2.4 Change in Consumers' Surplus Attributable to Pesticides

The ultimate objective of the analysis in this section is the measurement of the value of the net internal benefit which accrues to society as a result of an increase in crop yield attributable to the application of a pesticide. As has been asserted previously, this value can be approximated reasonably by:

$$\Delta CS_{ijt} = \Delta P_{ijt} \cdot Q_{j,t-1} + 1/2 \cdot \Delta P_{ijt} \cdot \Delta Q_{ijt}$$

where: ΔCS_{ijt} = the estimated change in consumers' surplus attributable to the application of pesticide i to crop j in year t,

ΔP_{ijt} = the change in the price of crop j attributable to the application of pesticide i in year t,

$Q_{j,t-1}$ = the total output of crop j in year (t-1), and

ΔQ_{ijt} = the change in the total output of crop j attributable to the application of pesticide i in year t.

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*Schultz, Henry, The Theory and Measurement of Demand, Chicago, Illinois, University of Chicago Press, 1938; and Western Extension Marketing Committee Task Force, A Handbook on the Elasticity of Demand for Agricultural Products in the United States, Western Extension Marketing Committee Publication No. 4, July, 1967.

Substituting into this expression the estimator of ΔP_{ijt} which has been derived in the preceding section produces the following final result:

$$\Delta CS_{ijt} = (P_{j,t-1} \cdot \Delta Q_{ijt})/E_j + 1/2 \cdot [P_{j,t-1} \cdot (\Delta Q_{ijt})^2] / (Q_{j,t-1} \cdot E_j)$$

where: ΔCS_{ijt} = the estimated change in consumers' surplus attributable to the application of pesticide i to crop j in year t,

$P_{j,t-1}$ = the price of crop j in year (t-1),

ΔQ_{ijt} = the change in the total output of crop j in the nation attributable to the application of pesticide i in year t,

E_j = the price elasticity of demand for crop j, and

$Q_{j,t-1}$ = the total output of crop j in year (t-1).

Thus, to estimate the benefit which accrues to society as a result of an increase in crop yield attributable to the application of a pesticide, the only information which is required is a determination of the price of the crop, an estimate of the increase in the total output of the crop which will be produced by utilization of the pesticide, a determination of the total output of the crop, and the value of the price elasticity of demand for the crop.

4.3 Costs of Pesticide Application

Since the measurement of the value of the net internal benefit as the consumers' surplus generated by an increase in yield appropriately incorporates all costs of pesticide application, there is no need to calculate these costs independently to determine the aggregate economic justifiability of registering a particular new pesticide. Yet, to the extent that independent calculation of these costs can provide valuable insights into the distribution of the net internal benefit among the suppliers and the users of the new pesticide, this calculation may be desirable for the assessment of the equity effects associated with the registration of this pesticide.

The total cost of applying a pesticide to a crop consists of two elements -- the cost of the pesticide which is applied and the cost of performing the application. The total cost of the pesticide which is applied can be estimated as:

$$TPC_{ijt} = R_{it} \cdot \sum_{k} (QP_{ijkt} \cdot NA_{ijkt} \cdot TCPA_{ijkt})$$

where: TPC_{ijt} = the total cost of the quantity of pesticide i which is applied to crop j in the nation in year t,

R_{it} = the price of pesticide i in year t,

QP_{ijkt} = the quantity of pesticide i applied per acre of crop j in region k per application of pesticide in year t,

NA_{ijkt} = the number of applications of pesticide i to crop j in region k in year t, and

$TCPA_{ijkt}$ = the total number of acres of crop j to which pesticide i is applied in region k in year t (estimated in subsection 4.2.1).

Estimates of the prices of pesticides which are used on large scales are important to the benefit-cost system because these prices vary from a few cents per pound of active ingredient to several dollars per pound of active ingredient. If the benefit-cost system is to identify adequately all costs associated with the registration of a proposed new pesticide, then the system must measure the costs which the farmers will have to bear in obtaining the new pesticide.

Perhaps the most reasonable method of obtaining estimates of the expected price of a pesticide which has never been offered for sale in the market is to require the manufacturer of the proposed new pesticide to divulge the price which he expects to charge for the pesticide if it is registered. However, if EPA is unwilling or unable to require the manufacturer to reveal this information, two alternative methods of estimating the probable price of a proposed new pesticide are offered for consideration:

- Match the proposed new pesticide with an existing pesticide, with which it is likely to compete; then project the trend of the existing pesticide price (per pound of active ingredient), or

- Average the historical price data for each year in a selected time period, for a group of pesticides which have been used on crops for which the proposed new pesticide is intended; then project the trend of this price average.

In any of these three cases, the expected price for the proposed new pesticide can be forecast either by projecting a straight line trend or by combining the base year data with selected variables from the OBERS* economic projections, which contain forecasts for 1980, 2000, and 2020. Obviously, these same forecasting techniques also would be applicable to the evaluation of a proposal for the reregistration of a pesticide, although in this case the forecasting techniques would be applied to historical price data for the pesticide under consideration.

In obtaining base year price data, it is likely that information from USDA sources, which is published several years after the prices have prevailed in the market, will be more convenient to utilize in the benefit-cost system than data from current price lists because of the difficulties inherent in collating, comparing, and compiling these current data into annual average figures. Moreover, data from the Annual Price Summary (op. cit., p. 168) incorporates state-level detail. Thus, different costs can be calculated for different states if this level of detail is desired.

The total amount of a pesticide which is purchased and applied in a year depends, in part, upon the quantity of the pesticide which is applied per acre in each application of the pesticide and the number of applications of the pesticide which are performed in that year. The application rate per acre and the frequency of application depend, in turn, upon the dosage rate specified on the label registered with EPA. Moreover, the frequency of application will also depend upon the

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*U. S. Water Resources Council, 1972 OBERS Projections, Washington, D.C., Superintendent of Documents, 1972 (see especially Volume 5).

recommendations of local extension agents and the farmer's assessment of the probable infestation of his crop. The maximum application rate and frequency of application which are recommended by EPA might be the most likely rate and frequency which will be selected by the farmer, but it is unlikely that the farmer will want to incur the expense of applying more pesticide than he thinks is really needed. Nevertheless, it is suggested that the benefit-cost system should concentrate on the EPA recommendations as sources of data concerning the application rate and frequency of application of a pesticide.

Finally, because of the possible development of immunity by specific pests to any pesticide, it is necessary to consider whether the rate of application per acre or the frequency of application would be likely to increase over a period of years. Data from two volumes of the Suggested Guide for the Use of Insecticides to Control Insects Affecting Crops, Livestock, Households, Stored Products, Forests, and Forest Products* indicate that the USDA continues to recommend a constant application rate per acre in successive years. Therefore, it is recommended that the assumption which is incorporated in the benefit-cost system should be that the application rate for any pesticide is likely to remain constant at least for three years and, probably, for five years. Given the continuing appearance of new pesticides on the market, substitution of one pesticide for another appears to be more likely to occur than a gradual increase of either the application rate or the frequency of application. Therefore, no specific allowance for the development of immunity has been incorporated into the benefit-cost system. An approach to introducing such an allowance is described by Hueth and Regev** and their model could be included as one of the component cells of the overall benefit-cost matrix if a consideration of the immunity phenomenon is desired.

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*USDA, Suggested Guide for the Use of Insecticides to Control Insects Affecting Crops, Livestock, Households, Stored Products, Forests and Forest Products, Washington, D.C., Superintendent of Documents, 1967, Agricultural Research Service and Forest Service, Agricultural Handbook Series No. 313, and 1969, Agricultural Handbook Series No. 331, p. 84, 1966, and pp. 83, 150-152, 1968.

**Hueth, D., and U. Regev, "Optimal Agricultural Pest Management with Increasing Pest Resistance," American Journal of Agricultural Economics, Vol. 56, No. 3, August, 1974, pp. 543-552.

The total cost of performing the application of the pesticide can be calculated as:

$$TAC_{ijt} = \sum_{k} (AC_{ijkt} \cdot NA_{ijkt} \cdot TCPA_{ijkt})$$

where: TAC_{ijt} = the total cost of performing the application of pesticide i to crop j in the nation in year t,

AC_{ijkt} = the cost per acre of performing the application of pesticide i to crop j in region k in year t,

NA_{ijkt} = the number of applications of pesticide i to crop j in region k in year t, and

$TCPA_{ijkt}$ = the total number of acres of crop j to which pesticide i is applied in region k in year t (estimated in subsection 4.2.1).

The methods of estimating both the expected frequency of application of a proposed new pesticide and the total number of acres to which the pesticide is expected to be applied have been described previously in this chapter. Consequently, the only new information which is required to evaluate this expression is information concerning the cost of performing the application of the pesticide, and reasonable estimates of this information, can be obtained from the agricultrual extension agents of each state. Hence, the total cost of applying a pesticide to a crop can be estimated as:

$$TC_{ijt} = TPC_{ijt} + TAC_{ijt}$$

where: TC_{ijt} = the total cost of purchasing and performing the application of pesticide i to crop j in the nation in year t,

TPC_{ijt} = the total cost of the quantity of pesticide i which is applied to crop j in the nation in year t, and

TAC_{ijt} = the total cost of performing the application of pesticide i to crop j in the nation in year t.

5.0 THE HEALTH EFFECTS SUBMODEL

5.1 Background

In the development of a benefit-cost methodology for use in the registration process of chemical pesticides, it is desirable to have a health effects submodel that will account for the occupational health effects, as well as the general public health effects associated with the development, manufacture, formulation, distribution, application, and residues of a particular pesticide product. Thus, the health effects submodel deals with the potential health effects of a pesticide with respect to the pesticide's registered use, and it contains procedures which can be applied wherever needed in the overall benefit-cost structure.

5.2 Outputs of the Health Effects Submodel

In order to make the purpose of this submodel more clearly understood, its desired outputs will be delineated. These outputs will be discussed in two parts -- health damages and health benefits.

5.2.1 Health Damages

In general, the outputs from this part of the submodel will be an identification and enumeration of the groups of people whose health would be damaged from both accidents and environmental exposure associated with a particular pesticide product.

More specifically, associated with each aspect of the pesticide product registration decision -- i.e., R and D, manufacture, formulation, distribution, application, and residues -- are potential occupational health damages and potential general public health damages to certain segments of the population. For example, in the manufacture and formulation of a pesticide for a particular use, there are potential acute health damages to the employees involved in this process. They may take one or more of the following forms:

- Acute injury from "normal" exposure,* i.e., irritation to skin, eyes, nose, and throat.

- Acute injury from accidental release under user controlled condition, i.e., poisoning, death or irritation to skin, eyes, nose, and throat.

- Acute injury from other abnormal involuntary exposure such as an explosion, i.e., poisoning, death, or irritation to skin, eyes, nose, and throat.

In addition, the subclinical injuries built up in one's body from continued exposure to a pesticide due to the manufacture and formulation process may cause chronic injury in one or more of the following forms:

- Mutagenicity,
- Teratogenicity,
- Oncogenicity,
- Reproductive impairment, and
- Chronic physiological malfunction.

These same acute and chronic injuries can occur in other segments of the population and as a result of other processes in the distribution and use of a pesticide product. The matrix in Exhibit 5.1 illustrates this concept in more detail, giving some possible causes of acute and chronic injury for the various processes and population subgroups.** By examining each aspect associated with the sale and

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*"Normal" exposure is included to reflect the real world situation. Ideally, there should be no such term as "acute injury from 'normal' exposure." Yet, many would argue, e.g., those in industry, that any acute injury that is caused from direct exposure to a pesticide is not all a result of accidental release. Therefore, until this issue is resolved, one can argue that some acute injury is caused by what many refer to as "normal" exposure.

**Note that the population subgroups exposed are dependent on the pesticide's purpose and location of use. For example, health hazards to field and farm personnel would only relate to those workers applying the particular pesticide product and not all farm workers. Likewise, only those segments of society in the vicinity of the

EXHIBIT 5.1: Health Damages from a Pesticide Product Registration Decision

Nature of Health Damage	Process Causing Health Damage				
	Research and Development	Manufacturing and Formulation	Distribution (Transportation and Storage)	Application	Residues*
Occupational Health Damages from contact with pesticides	Acute injury caused by normal exposure** in the laboratory or field, accidental releases in the laboratory or field, etc.	Acute injury caused by normal exposure,** accidental releases, explosions, etc.	Acute injury caused by normal exposure,** accidental releases, or other transportation accidents	Acute injury caused by normal use,** accidental releases, misuse, equipment failure, etc.	Chronic injury caused by long-term occupational exposure***
General Public Health Damages from contact with pesticides	Acute injury caused by drift from accidental releases as a result of experimental use permits	Acute injury caused by drift from accidental releases, explosions, etc.	Acute injury caused by drift from accidental releases or other transportation accidents	Acute injury caused by drift from accidental releases or misuse by a professional applicator and caused by normal use,** accidental releases or misuse by the household user	Chronic injury caused by long-term exposure via buildup in food chains, etc.

*Residues from direct contact with pesticides can be brought about as a byproduct of the R&D, manufacture, formulation, distribution or application processes. However, only the application process is a major contributor to residues from indirect contact with pesticides.

**"Normal" exposure is included to reflect the real world situation. Ideally, there should be no such term as "acute injury from 'normal' exposure (use)." Yet, many would argue, e.g., those in industry, that any acute injury that is caused from direct exposure to a pesticide is not all a result of accidental release. Therefore, until this issue is resolved, one can argue that some acute injury is caused by what many refer to as "normal" exposure.

***This chronic injury includes only those injuries caused by residues from direct long-term exposure as a result of direct contact with a pesticide, whether it be from the R&D, manufacture, formulation, distribution or application processes. Thus, chronic injury from residues from indirect long-term exposure as a result of indirect contact, i.e., from daily food intake, is not included here, but in the box below.

use of a pesticide product, the distributional effects can be assessed, rather than just the total occupational health damage or general public health damage. That is, those population segments most likely to be affected can be delineated. This is important as EPA regulatory activities, in general, are inevitably concerned with equity questions. These questions are often crucial issues in EPA cancellation hearings. However, available data on health damages may not be sufficient to allow for an analysis as shown in Exhibit 5.1.

Nevertheless, the distributional health effects indicated in Exhibit 5.1 may be restructured in such a way as to provide meaningful information. For example, those population segments most likely to incur either occupational health damage or general public health damage can be delineated based upon the processes causing health damage. Furthermore, the acute and chronic injuries as outlined above can be specified as the second dimension to the problem. Exhibit 5.2 provides a structure for this approach. The assessment of each type of health damage for each subpopulation incurring health damage can provide a profile of the distributional health effects associated with a pesticide registration decision.

However, in order to make an intelligent assessment of these injuries, definitions of these acute and chronic injuries are needed. Furthermore, two sets of definitions are desirable -- the first based on human experience data and the second based on experimental toxicology data. Therefore, presented below is one attempt to define these injuries so that an assessment of the human health damage from a pesticide product registration can be made.

The definitions appearing in Sections 5.2.1.1 and 5.2.1.2 have been based on the expert opinion of Dr. Henry F. Smyth, Jr., toxicologist and Advisory Fellow, Mellon Institute. Furthermore, those in Section 5.2.1.2 are consistent with the current experimental testing procedures required by the EPA Registration Guidelines and have been derived to follow the "Toxicity Categories" tabulation in the EPA "Proposed Registration, Reregistration and Classification Procedures,"

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manufacturing or application of the particular pesticide product are in danger of possibly incurring acute injury from indirect contact. In addition, household users and non-farm applicators would not be affected by a pesticide if used for farm use only.

EXHIBIT 5.2: Delineation of Health Damages from a Pesticide Product Registration Decision

Entity Incurring Health Damage	Type of Health Damage										
	Acute Injury						Chronic Injury				
	Morbidity										
	Ocular Exposure Hazard	Dermal Exposure Hazard	Oral Exposure Hazard	Inhalation Exposure Hazard	Systemic Poisoning	Mortality (Death)	Mutagenic Hazard	Terato-genic Hazard	Oncogenic* Hazard	Reproduc-tive Im-pairment	Physiologic Malfunction Hazard*
Occupational Health Damage to:											
Pesticide R&D Manufacturing and Formulation Workers											
Pesticide Transport Personnel											
Field Workers and Other Farm Personnel											
Commercial Farm Applicators											
Professional Non-Farm Applicators (PCO's, government employees, etc.)											
General Public Health Damage to: Household Users of Pesticides (through direct exposure)											
Society as a Whole (through indirect exposure)											

*In particular, with respect to central nervous system, hematopoetic system, liver and kidneys.

Federal Register (Vol. 39, No. 201, October 16, 1974, p. 36986). Needless to say, other experts in this field may agree or disagree with these definitions and thus they do not nor are they intended to represent the opinion of all experts. Nevertheless, definitions of this sort are necessary and those that appear below are workable definitions consistent with the current state-of-the-art.

5.2.1.1 Definition of Health Damages Based on Human Experience Data

The definitions below are based on the incidence of the particular injury. Incidence is used in the epidemiological sense as the number of individuals affected among each 100,000 exposed to the pesticide product* in the subpopulation indicated by the left-hand line headings of Exhibit 5.2.

Therefore, ocular exposure hazard, dermal exposure hazard, oral exposure hazard, inhalation exposure hazard, and systemic poisoning can respectively be defined as the incidence of irritation to the eyes, irritation to the skin, irritation to the throat from swallowing, irritation to the nose from inhaling and any adverse response to absorption through the skin, by mouth and/or by inhalation, attributed to the pesticide product and sufficiently severe to cause:

- The victim to purchase and apply an ameliorative preparation, or
- The victim to seek medical advice or treatment, or
- The victim to lose time from work.

The column headed "death" can be defined as the incidence of reported deaths attributed to exposure to the pesticide product.

Under "chronic injury," mutagenic and teratogenic hazards must be assessed simultaneously because the distinction between mutagenesis and teratogenesis depends on whether DNA is altered, and this is not routinely reported for isolated human cases. Therefore, combining

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*If information on the pesticide product is not available, then data on the pesticide in general should be compiled. This information can then be used to determine the marginal health effects of the pesticide product based on the particular use of the pesticide and the percentage of the pesticide used for this particular use.

these terms under the title of "hazard to offspring," they can be defined as the incidence of stillbirths and abnormal offspring attributed to exposure of either parent to the pesticide product. Oncogenic hazard can be defined as the incidence of neoplasms attributed to past exposure to the pesticide product, and reproductive impairment can be defined as the incidence of reduction in fertility and of neonatal mortality attributed to exposure of either parent to the pesticide product. Finally, physiological malfunction hazard can be defined as the incidence of malfunction of any body organ or system attributed to exposure to the pesticide product, provided that it is sufficiently severe to cause:

- The victim to purchase and apply an ameliorative preparation, or
- The victim to seek medical advice or treatment, or
- The victim to lose time from work.

Data describing the numbers of people in each subpopulation who experienced these effects can only be available for presently or previously registered pesticide products and thus these definitions can only be applicable for those pesticide products seeking reregistration and for those new pesticide products whose parallel pesticide* is a presently or previously registered pesticide product. There can be three main sources of these data:

- Planned and controlled administration of pesticides to human subjects,**
- Case reports of episodes of accidental or other acute poisoning, and
- Epidemiological studies which, in turn, comprise surveys of occupationally-exposed groups (in accordance with a variety of retrospective and prospective approaches) and studies of the general population.

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*Definition of this term appears in Chapter 2.0 of this report.

**This source is no longer acceptable and therefore any information obtained in this manner will have already been reported on.

Computerized searches, such as MEDLINE and TOXLINE, and manual searches of the Pesticides Abstracts and other pertinent sources -- e.g., medical journals, EPA's Pesticide Episode Reporting System (PERS), poison control centers, etc. -- can provide access to these data, as they exist. Experience has indicated, however, that the fact that a pesticide is or has been registered, does not mean that data related to its health effects will be available. For most pesticides, little is known about their human health effects, particularly when populations are exposed to long-term, low level doses of the pesticide. Furthermore, when using a parallel pesticide, it may be possible that the parallel has not been in use for a long enough time period to adequately assess potential health effects of the new pesticide. Therefore, a continuing review of these types of data will be necessary to achieve full completion and adequate updating of Exhibit 5.2, using the definitions defined in this subsection. That is, the following sorts of information concerning human exposure to a particular pesticide or pesticide product must be continually sought and updated to properly compute incidences of those hazards delineated in Exhibit 5.2:

- Numbers of exposed people in each subpopulation,
- Nature of health damage, i.e., occupational or general public,
- Type of physiological effects,
- Types of illnesses or disabilities,
- Number of reported deaths and poisonings,
- Type of application associated with accident or exposure, and
- Nature of treatment, e.g., number of days in a hospital, number of visits to a physician, medication taken, etc.

However, in using the above definitions, indications are that the column which might be filled in with best quantitative accuracy at present is that headed "death." Death certificates can be screened, and correspondence can (often) narrow down to specific pesticides and subpopulations those certificates which are ambiguous. Qualitative information may be obtained for the other columns by a thorough search of the medical literature and records of poison control centers as mentioned above, but it is doubtful that reasonably complete quantitative information can be obtained, given present medical and health reporting procedures.

5.2.1.2 Definition of Health Damages Based on Experimental Toxicology Data

When registration is being sought for a new pesticide product, adequate human experience data will naturally not be available. If a parallel pesticide product exists, then human experience data for this parallel registered product can be used to the extent available. However, experimental toxicology data are essential to adequately identify the parallel pesticide(s). Furthermore, if a new pesticide product has no parallel registered product, experimental toxicology data required by the registration process must be used to assess the likely human health effects.

There is world-wide acceptance of the arbitrary "factor of safety" of 100 which was first proposed by A. J. Lehman of the Food and Drug Administration for dealing with new substances to which the human race has not yet been exposed extensively, and was published in the Federal Register of March 11, 1955 (p. 1493). It is now applied to all substances as a conservative factor between animal experiment and human tolerance, except when a lower factor may be justified because it is known that the system injured by the substance responds nearly equally in different species, such as cholinesterase, or corneal and skin injury. It is quite obvious that the number 100 may be too high for some substances and too low for others. The only way to get a more defensible number is to determine the relative resistance of the target system to the substance or, almost as good, to select an experimental species which biotransforms the substance qualitatively and quantitatively like the human.

Legally required precautionary labels warn how to avoid injury from reasonably foreseeable hazards of handling pesticides. Injuries in subpopulations which handle a pesticide in its original container generally result from failure to follow the directions and precautions for use. Predicting incidence for these subpopulations is essentially predicting the frequency of failure to follow directions. However, it is not unreasonable to assume that this frequency is the same for all pesticides, and that experimental animal results measure the relative incidence of severe injuries among the careless due to toxicity of the chemical, hence, the relative frequency of severe injuries between different pesticides. This argument does not hold for the subpopulation whose exposure to the pesticides is due to residues in food, water, and air, because these people never see the labels, and are not injured due to their own carelessness.

The number of injuries reported in the medical literature for subpopulation groups (if available) can be combined with estimates of the size of the groups exposed to the pesticide product and the published experimental animal results, to refine the estimates which would be generated by the definitions below. Therefore, the definitions are more valid as patterns than as a means to make accurate numerical estimates.

For acute injury, each hazard defined below contemplates injuries similar to those in Section 5.2.1.1 and thus sufficiently severe to cause:

- The victim to purchase and apply an ameliorative preparation, or
- The victim to seek medical advice or treatment, or
- The victim to lose time from work,

In addition, each hazard can be expressed as the number of individuals affected among each 100,000 exposed to the pesticide product in the subpopulation indicated by the left-hand headings of Exhibit 5.2. Furthermore, due to the uncertainty of extrapolating from animal toxicology data to likely human health effects, a range for each hazard that incorporates the probable value of each hazard is desirable.* Therefore:

- Ocular exposure hazard is defined as eight to twelve times the number of rabbit eyes among six tested which suffered irreversible opacity at two days, plus four to six times the number which suffered corneal opacity reversible within two days or irritation persisting for seven days, plus 0.5 to 1.5

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*The basis for these definitions has already been explained (see the last paragraph on page 5.4).

times the number which suffered irritation reversible within seven days, when ocularly exposed with 0.1 ml of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest.

- Dermal exposure hazard is defined as eight to twelve times the number of rabbits among six tested which suffered necrosis or marked erythema evident at 72 hours, plus four to six times the number which suffered moderate erythema evident at 72 hours, plus 0.5 to 1.5 times the number which suffered any visible lesser degree of irritation evident at 72 hours, when dermally exposed -- i.e., when applied to both covered and uncovered skin, both intact and abraded -- with 0.01 ml of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To the sum of these three degrees of primary irritation should be added eight to twelve times the number of guinea pigs sensitized to any degree among a group of 10 tested to account for the dermal sensitizing potential of the pesticide product.

- Oral exposure hazard is defined as 100 divided by the rat oral LD_{50} (expressed in ml/kg body weight) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range for this hazard, one can use the mean LD_{50} and the 95 percent confidence interval LD_{50}'s.

- Inhalation exposure hazard is defined as 4,000* divided by the 4-hour rat LC_{50} (expressed as milligrams per liter of air) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range for this hazard, one can use the mean LC_{50} and the 95 percent confidence interval LC_{50}'s.

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*This number was derived so that the resulting oral exposure hazard and inhalation exposure hazard would be equivalent for an oral LD_{50} and an inhalation LC_{50} that are equally toxic according to the "Toxicity Categories" tabulation in the October 16, 1974, Federal Register.

- Systemic poisoning hazard is defined as the sum of oral exposure hazard, percutaneous exposure hazard* and inhalation exposure hazard for the subpopulation of interest. **

- Death hazard is defined as one-twentieth of the systemic poisoning hazard for the subpopulation of interest. ***

For the five chronic injury hazards, each can be defined as the expected incidence in humans empirically extrapolated from experimental animal data. To empirically extrapolate from animal data, for a particular chronic effect, the following can be done:****

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*Percutaneous exposure hazard is defined as 100 divided by the rabbit percutaneous LD_{50} (expressed in ml/kg body weight) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range for this hazard, one can use the mean LD_{50} and the 95 percent confidence interval LD_{50}'s. In addition, percutaneous exposure is assumed to produce systemic poisoning.

**Systemic poisoning can occur via the oral, dermal penetration or inhalation routes of entry. This definition assumes that for each person experiencing irritation by oral or inhalation exposure, there will be an additional person more severely exposed such that systemic poisoning will result. Therefore, these two exposure hazards are added to percutaneous exposure hazard.

***Death can occur via the oral, dermal penetration or inhalation routes of entry just as systemic poisoning. This definition assumes that for every 20 persons experiencing systemic poisoning, there will be an additional person more severely exposed such that death will result.

****This procedure is based upon the probit model which has been used by many in carcinogen testing of pesticides. For example, see N. Mantel and W. R. Bryan, "Safety Testing of Carcinogenic Agents," Journal of the National Cancer Institute, Vol. 27, 1961, pp. 455-470. Other models which may be used include the Logistic and One-Hit Models. For a further discussion of all three models, see Agriculture-Environmental and Consumer Protection Appropriations for 1975, Part 8, Food and Drug Administration, "Study of the Delaney Clause and Other Anti-Cancer Clauses," pp. 400-436.

- Calculate a regression line in terms of logarithm oral dosage (in mg/kg) vs. probit incidence from a study yielding fractional incidence, preferably less than 50 percent, of the chronic effect in question -- e.g., mutations -- for each of two groups of experimental animals, preferably one a rodent (e.g., rat) and one a primate (e.g., monkey). These will be lines displaced from each other on the dosage axis and they will probably have different slopes.
- Construct a "human analog" curve midway between these two curves, and of intermediate slope.
- Calculate the expected average daily intake (for all routes of entry) for the human subpopulation of interest.
- Multiply this expected average daily intake by 100 and determine the incidence of the chronic effect in question for this dosage level by using the "human analog" curve generated above.
- This incidence can be used as the incidence of the chronic effect in question for the subpopulation of interest.

If the "human analog" curve described above is generated using experimental animals of a species which is known to metabolize small dosages of the pesticide by the same pathways, and to approximately the same extent, as do humans, then the safety factor of 100 would not be needed. However, it is unlikely that data of this nature are available; thus, the reason for using the safety factor.

The necessary data to perform the above assessments consist of the following:

- Animal test studies on rats, rabbits, monkeys, and other species where acute and chronic injuries are assessed when subjected to the pesticide product using various types of exposure -- i.e., dermal, oral, ocular, and inhalation -- and various degrees of exposure.

- Expected average daily intake for the various subpopulations from exposure to the pesticide product. For those occupationally or directly exposed, this includes the expected daily oral, dermal, ocular, and inhalation exposure, as well as the expected average daily dietary intake. For those indirectly exposed, the primary intake will be the average daily dietary intake.

Various sources are available to obtain the above information. The primary source is the registration process and a secondary source is the published literature. For example, the animal test studies may be available in the toxicology literature but should also be provided in the information supplied by the petitioner of a pesticide product registration. Furthermore, the petitioner seeking to register a pesticide product should provide information concerning the daily expected oral, dermal, ocular, and inhalation exposure based upon the application process and rate necessary for the product to be efficacious. The expected average daily dietary intake from use of the pesticide product can be determined based upon allowable tolerances for residues in raw agricultural food and feed affected by the product, the expected residues once the food is processed and the daily human diet. The allowable tolerances must be provided in the registration process and information to convert tolerances into expected average daily dietary intake can be obtained through market basket studies, food processing firms, processed food samples, and human diet studies.

Although the above definitions are not based upon intricate manipulations of the experimental animal data, they do provide a means of using these data. Since many new pesticide products will not have "parallel" products, there is no other alternative but to use these animal data in completing Exhibit 5.2. At the least, they should provide insights into the relative likelihood of various acute and chronic injuries occurring. At best, if the numbers generated by these definitions are coupled with any available human exposure data generated by Section 5.2.1.1, then accurate estimates of acute and chronic injury may be possible.

5.2.1.3 Refinement and Quantification of Health Damages

As indicated in the discussion in Sections 5.2.1.1 and 5.2.1.2, the health damages assessment could be as detailed as the numbers of persons in each category incurring various types of health damages; or simply an assessment of whether the likelihood of the hazard is highly probable, somewhat probable or not probable at all for each cell in Exhibit 5.2.

Once these health damages have been assessed as outlined in Sections 5.2.1.1 and 5.2.1.2, further analysis of matrix cells should be made, if at all possible. That is, if certain segments of society bear greater health hazards than others, then the entity "society as a whole" should be refined to reflect these differences, perhaps using an age-sex breakdown. In addition, if geographic differences are indicated, based on application procedures, then these too should be delineated if possible.

Finally, attempts will have to be made to transform these probabilities and/or numbers of people most likely incurring the health damage into monetary values. Furthermore, if these health damages will occur sometime in the future, as with chronic injuries, they may be discounted in order to obtain their present value as discussed in the theoretical presentation of Chapter 3.0.

The proper measure of health damages is the value of reducing the probability of ill health by a marginal amount.* This marginal amount, however, is difficult to measure. Alternatively, the human capital approach can be used, although theoretically incorrect according to Dr. Lave. Nevertheless, it is logical that a lower bound on the value of health damages is the loss in productivity due to acute and chronic injury.**

In addition to this lost productivity, one can further quantify health damages by measuring the cost of restoring the people who are "sick" to good health. The difficulty of this measurement is determining the numbers of people afflicted for each unit of pollution, and, in the case of accumulation of pesticide residues within the body (i.e., long-term exposure), the actual amount of illness or affliction that occurs. However, with respect to occupational health damages, both acute and chronic, one may argue that they are a cost to the manufacturer, formulator, distributor, and professional applicator, and are thus reflected in the price of their product or service. This will be true to the extent that the employer provides medical coverage and/or insurance for his employees, to the extent that the employees demand higher wages or pensions due to the occupational risks involved, and to the extent that the employer incurs some cost in employee replacement, when employees are disabled or retire sooner than otherwise expected. Therefore, for occupationally-exposed persons, health damages may be estimated as the cost measurement for restoring people who are sick to good health, reflected, in part, by medical coverage insurance premiums, differential wage rates, increased pensions, etc. If these expenses are incurred by the employer, care must be taken to insure that they are not included twice, i.e., here and again in the price of their product of service.

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*From personal correspondence with Dr. Lester Lave, Head, Department of Economics, Carnegie-Mellon University.

**This is only a lower bound because consumers' surplus is not included in such a calculation.

When trying to quantify health damages for a pesticide product, all three methods of estimating the monetary values of health damages will be considered, i.e.:

- Value of reducing the probability of ill health by a marginal amount,
- Value of lost productivity, and
- Value of remedial health care and services.

Once the data is generated outlining the health problems related to use of a pesticide product, monetary evaluation will proceed, if possible, using that (those) method(s) that would give the most accurate forecast of the health implications of a pesticide product registration decision.

Numerous sources are available that have attempted to put monetary values on health damages, both short-term and long-term. Listed below are selected references where representative information may be obtained:

- Acton, Jan, Evaluating Public Programs to Save Lives: The Case of Heart Attacks, RAND Corporation, January, 1973 (includes an extensive bibliography).

- American Hospital Association, Hospital Statistics.
- American Medical Association.
- Arrow, K., and M. Kurz, Public Investment, The Rate of Return and Optimal Fiscal Policy, Baltimore, Johns Hopkins Press, for Resources for the Future, 1970.
- Baumol, W., "On the Social Rate of Discount," AER, Vol. 58, 1968, pp. 788-802.
- Mushkin, S., "Health as an Investment," Journal of Political Economy, Vol. 7, No. 5, Part 2, October, 1962.
- Rice, Dorothy, Estimating the Cost of Illness, Health Economics Series #6, DHEW, 1966 (PHS Publication No. 947-6).

5.2.2 Health Benefits

Health benefits from a pesticide product registration result from the application and remaining residues of a pesticide. More specifically, the majority of the health benefits accrue to the general public as a result of increased food, feed, and fiber production, or decreased health/disease vector control problems. Thus, health benefits can be characterized by the following:

- Less disease, more healthful population,
- Happier, more content people,
- More productive population, and
- Lower medical expenses.

Measurement of these characteristics is once again very difficult to accomplish. The approach to be employed will attempt to calculate the health damages that would result if the pesticide product registration was denied. It is likely, however, that these health damages would be a different severity and frequency than those caused by the use of a pesticide. Nevertheless, if the registration were denied, it is possible that a health/disease vector control problem would go uncontrolled or that a decreased food supply would result from decreased yields in the absence of the pesticide.

The magnitude of each of these possibilities can be estimated -- e.g., by using the agricultural submodel to determine the decreased food supply or by using insect pest population forecasts to predict the health/disease vector control problem. They can then be translated into the possible health damages that they may have on the general population. The majority of effects would most likely be increased illness, possibly resulting in death or a chronic physiologic malfunction problem. Therefore, health benefits from use of a pesticide can be viewed as the illness and/or death and/or chronic health problems that would result if the pesticide was, in fact, not registered. These damages can be assessed using similar definitions as those developed in Section 5.2.1.1, "Definition of Health Damages Based on Human Experience Data." In this instance, however, the effects would be attributable to the non-use of the pesticide, rather than exposure to the pesticide.

Monetary quantification can once again be assessed using the procedures outlined in Section 5.2.1.3. However, it may be a more formidable task as the health damages caused by the absence of using a pesticide will probably not be as well defined as those caused by exposure to a pesticide.

5.3 Inputs to the Health Effects Submodel

In order to properly assess the outputs of the health effects submodel, various input data are required, some of which were indicated in Section 5.2. These data will consist of the following information, either presently required by the registration process or that should be required by the registration process:

- Information on (proposed) pesticide manufacturing process,
- Formulation process for the intended registered use,
- Distribution -- i.e., transportation and storage -- of pesticide product,
- Method(s) of application,

- Volume of application, i.e., frequency, rate, and timing,
- Disposal of pesticide and pesticide containers,
- Human exposure data documenting any known human effects that have occurred,*
- Toxicity, persistence, and mobility of pesticide and pesticide product,
- Mutagenicity, teratogenicity, and oncogenicity of pesticide product in experimental animals, i.e., animal feed studies, reproduction studies, etc.,
- Tolerances for residues in raw agricultural food and feed,
- Probable accumulation in human tissue, i.e., biological half-life,*
- Expected long-term exposure data, i.e., based on application rate, expected dermal, ocular, oral, and inhalation exposure for the various subpopulations directly exposed to the product.*
- Description of pest populations being controlled,
- Efficacy of pesticide, and
- Numbers of people possibly exposed by subpopulation groups.*

The use of some of this input data has been discussed earlier and is further discussed in the following section.

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*Not presently required by registration process.

5.4 Relating Inputs and Outputs of the Health Effects Submodel

Now that the inputs and outputs of this submodel have been delineated, the relationships between the two will be more fully addressed. These relationships are extremely complex as illustrated in Exhibit 5.3, which presents a simplified flow diagram that links the necessary inputs to the desired outputs. Most of the terms in the exhibit have been previously defined in this chapter or in the registration regulations. For those that are still undefined, definitions appear below:

- Threshold Limit Value (TLV) -- The maximum time-weighted pesticide concentration to which industrial workers may be exposed in the work environment for a 7 or 8 hour day and a 40-week week; given in milligrams of substance that may be found per cubic meter of workroom.*

- Fatal Dose in Man -- The estimated amount of pesticide that can kill a 70 kg man.**

- Permissible Criteria for Drinking Water in Man -- The maximum permissible level of a pesticide which may be found in drinking water, which, if ingested over extended periods, is not expected to cause harmful or adverse physiological changes in man.***

- Maximal Acceptable Daily Intake in Man -- The maximum acceptable daily intake of pesticides in food, which, if ingested over a lifetime, is not expected to cause harmful or adverse physiological changes in man.****

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*American Conference of Governmental Industrial Hygienists.

**Hayes, W. J., Clinical Handbook on Economic Poisons, U.S. DHEW, PHS Publication No. 476, Reprint, January, 1967.

***PHS Advisory Committee on Use of the PHS Drinking Water Standard.

****FAO/WHO, Evaluation of the Toxicity of Pesticide Residues in Food, 1965.

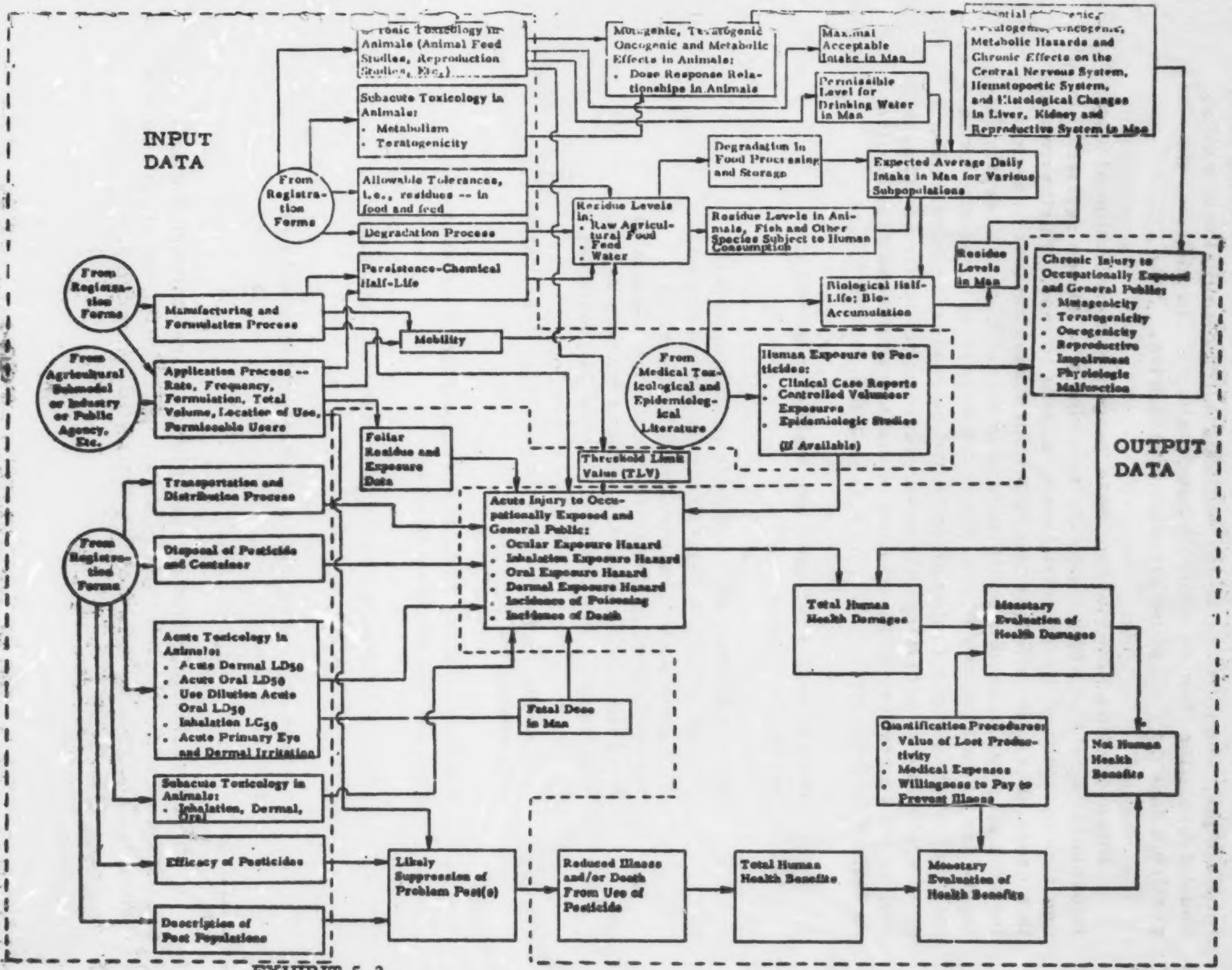
INPUT DATA
OUTPUT DATA
From Registration Forms
Chronic Toxicology in Animals (Animal Feed Studies, Reproduction Studies, Etc.)
Subacute Toxicology in Animals:
• Metabolism
• Teratogenicity
Allowable Tolerances, i.e., residues -- in food and feed
Degradation Process
Persistence-Chemical Half-Life
Mutagenic, Teratogenic Oncogenic and Metabolic Effects in Animals:
• Dose Response Relationships in Animals
Maximal Acceptable Intake in Man
Permissible Level for Drinking Water in Man
Potential Mutagenic, Teratogenic, Oncogenic, Metabolic Hazards and Chronic Effects on the Central Nervous System, Hematopoetic System, and Histological Changes in Liver, Kidney and Reproductive System in Man
Degradation in Food Processing and Storage
Expected Average Daily Intake in Man for Various Subpopulations
Residue Levels in:
• Raw Agricultural Food
• Feed
• Water
Residue Levels in Animals, Fish and Other Species Subject to Human Consumption
Residue Levels in Man
Biological Half-Life; Bio-Accumulation
Chronic Injury to Occupationally Exposed and General Public:
• Mutagenicity
• Teratogenicity
• Oncogenicity
• Reproductive Impairment
• Physiologic Malfunction
From Registration Forms
Manufacturing and Formulation Process
Mobility
From Agricultural Submodel or Industry or Public Agency, Etc.
Application Process -- Rate, Frequency, Formulation, Total Volume, Location of Use, Permissable Users
From Medical Toxicological and Epidemiological Literature
Human Exposure to Pesticides:
• Clinical Case Reports
• Controlled Volunteer Exposures
• Epidemiologic Studies
(If Available)
Foliar Residue and Exposure Data
Threshold Limit Value (TLV)
From Registration Forms
Transportation and Distribution Process
Disposal of Pesticide and Container
Acute Injury to Occupationally Exposed and General Public:
• Ocular Exposure Hazard
• Inhalation Exposure Hazard
• Oral Exposure Hazard
• Dermal Exposure Hazard
• Incidence of Poisoning
• Incidence of Death
Total Human Health Damages
Monetary Evaluation of Health Damages
Acute Toxicology in Animals:
• Acute Dermal LD50
• Acute Oral LD50
• Use Dilution Acute Oral LD50
• Inhalation LC50
• Acute Primary Eye and Dermal Irritation
Fatal Dose in Man
Quantification Procedures:
• Value of Lost Productivity
• Medical Expenses
• Willingness to Pay to Prevent Illness
Net Human Health Benefits
Subacute Toxicology in Animals:
• Inhalation, Dermal, Oral
Efficacy of Pesticides
Description of Pest Populations
Likely Suppression of Problem Pest(s)
Reduced Illness and/or Death From Use of Pesticide
Total Human Health Benefits
Monetary Evaluation of Health Benefits

EXHIBIT 5.3

Flow Diagram of Information Needed for Assessment of Health Effects Due to a Pesticide Product Registration Decision

91<

As can be seen from Exhibit 5.3, specification of each of these relationships (i.e., the arrows) would be a difficult and time-consuming task, for example, when looking at chronic effects from animal test studies and extrapolating them to possible human effects. In addition, the available data may not allow for such an exercise.

However, this flow diagram does serve as an indication of what information would be appropriate in reviewing a pesticide registration decision in terms of its potential health effects to man. Furthermore, in a gross sense, it indicates how this information relates to assessing both acute and chronic health effects in man. That is, certain data inputs are more applicable than others for assessing these effects in man and emphasis should therefore be put on reviewing information most applicable to achieving this goal. More specifically, emphasis will be put on reviewing information necessary to assess health effects as defined in Sections 5.2.1.1, 5.2.1.2, and 5.2.1.3, i.e.:*

- Size of each subpopulation possibly exposed to pesticide product.
- Human exposure to pesticide (a minimum will involve human health effects from experimental data generated from the R and D effort. If a reregistration or "parallel" pesticide product is involved, then additional human exposure data on known human health effects would be available).
- Acute toxicology in test animals (both quantitative and qualitative aspects).
- Subacute toxicology in test animals (both quantitative and qualitative aspects).
- Chronic toxicology in test animals (both quantitative and qualitative aspects).
- Mutagenic, oncogenic, and teratogenic effects in test animals.

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*Note that this information should be required through the data requirements of the registration process. Presently, not all this information is required, as indicated previously in Section 5.3.

- Expected average daily intake in man for various subpopulations (based on tolerances for residues in raw agricultural food and feed and additional intake from oral, dermal, ocular, and inhalation exposure from direct exposure to pesticide).

In addition, attempts will be made to only rely on results from an experimental species whose target organ or body system for the particular pesticide in question reacts quantitatively and qualitatively like those of man; or almost as satisfactory which biotransforms the particular pesticide quantitatively and qualitatively as does man.

5.5 Application of the Health Effects Submodel

Sections 5.2 through 5.4 have outlined the health effects submodel in some detail. In this section, a description is given concerning how this model should be used.

When a new or presently registered pesticide product is being considered for registration or reregistration, respectively, the health effects must be delineated for both this pesticide product and its next best alternative. These should be done by looking at the health effects of the new or presently registered pesticide versus no pesticide and the health effects of the next best alternative versus no pesticide, for a period of at least five years.

More specifically, in projecting the likely health effects of registering a new pesticide product, input data for this new pesticide product can be used as outlined in Section 5.2.1.2 to obtain an indication of the pesticide's likely human health effects. In addition, this input data could be compared to input data for other similar pesticide products already registered and used, in order to find a presently registered and used pesticide product that is parallel to the new pesticide product seeking registration.* Once this were accomplished, available "hard" output data for the parallel registered and used pesticide product can be assessed, using definitions in Section 5.2.1.1, to offer additional evidence of what the likely human health effects of registering

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*The method of comparison is discussed in Chapter 2.0 of this report.

the new pesticide product would be. In the case of a pesticide product seeking reregistration, greater emphasis can be put on human experience data than on experimental animal data. These potential health effects can then be outlined as in Exhibit 5.2, followed by monetary quantification described in Section 5.2.1.3, if possible.

Next, the health effects of the next best alternative must be assessed, following the definitions set forth in Sections 5.2.1.1 and 5.2.1.2. Once again, these potential health effects can be outlined as in Exhibit 5.2, followed by monetary quantification described in Section 5.2.1.3, if possible.

Then, these two sets of health effects can be compared to see the tradeoffs involved in reregistering a pesticide product or registering the new pesticide product versus its next best alternative versus no pesticide. The ultimate assessment of the health effects data vis-a-vis a general use or restricted use registration of the pesticide product must lie with the Administrator of EPA. He must decide the relative importance of the health effects and what subpopulations are most important to consider. These decisions can be made by considering the numbers of people who may be at risk, the incidence of the health effect and/or the severity of the health effect when it occurs. Thus, if the number of people who may be at risk is the critical factor, then chronic injury would be most important. If incidence and severity of the effect is most important, then acute injury would take precedence. A weighting scheme could be devised by the Administrator based upon his views of the relative importance of each of these factors.

Assuming that a new pesticide product is registered, those that are occupationally exposed should be monitored so that human experimental data can be compiled concerning the health effects from exposure to the pesticide. In addition, this should be a requirement for pesticides seeking reregistration. By insisting on this surveillance system, any health effects likely to be incurred by the human population will be indicated, as those who are occupationally exposed to the pesticide would be the first to show signs of human health effects.

6.0 THE ENVIRONMENTAL EFFECTS SUBMODEL

6.1 Conceptual Structure and Assumptions

In addition to the human health effects discussed in Chapter 5.0, many impacts of pesticides have been detected in the environment in contexts or at levels where they do not impinge directly on human well-being, but they do, in fact, impinge on non-target species and wildlife which are of valid human concern.

It is possible to fully agree with Rene Dubos who has said that we need to save condors not for the sake of the condors, but for the sake of learning enough about ourselves and our social mechanisms in order to be able to save condors. But there are more direct reasons for developing a benefit-cost system for pesticides which incorporates ecologic factors. A succinct statement of this problem was provided in 1965 by the Panel appointed by President Lyndon Johnson:

> "Man is but one species living in a world with numerous others; he depends on many of these others not only for his comfort and enjoyment but for his life. Plants provide the principal mechanism whereby energy from the sun can serve the earth's inhabitants. In doing so, they maintain the oxygen content of the air and furnish the basic habitat and food of animals and men. Microorganisms -- bacteria, algae, fungi, and protozoa -- perform a myriad of essential functions including the purification of air, soil, and water, and the recycling of nutrients. Animals serve man as great converters, changing plant-stored energy into forms of food he prefers and supplying him with a wide variety of materials: leather and furs, oils and pharmaceuticals, ivory and pearls, bristles and wool. Many insects are beneficial, some as pollinators; others as predators on harmful forms; some as makers of silk and honey.
>
> As contributors to happiness and the quality of life, plants and animals provide opportunities for enjoyment of natural beauty, for hunting, fishing, gardening, scientific study, entertainment, and the satisfaction of our human curiosity.

> In the control of pollution, plants, animals, and microorganisms are directly useful in two ways: First, living things, especially microorganisms, have a capacity for absorption and decomposition of pollutants, with resulting purification of air, water and soil. Second, many species of organisms, each with its own particular range of sensitivity to each pollutant, stand as ready-made systems for environmental bioassay and monitoring, and for warnings of danger to man and his environment. Because living things are interdependent and interacting, they form a complex, dynamic system. Tampering with this system may be desirable and necessary, as in agriculture, which involves artificial manipulation of the balances of nature on a huge scale. But such tampering often produces unexpected results, or side effects, and these are sometimes very damaging. Many of the effects of pollution fall into this category."*

The statement by the Environmental Pollution Panel provides a key to the reasons for valuing plants, insects, and wildlife. However, it also leaves a large gap in the development of specific benefits and costs for detailed analysis of pesticide impacts. Pesticide effects on non-target species are of valid concern to society, and, in general, should be accounted as social costs incurred in the course of pesticide use. More specifically, these effects are generally seen to reduce the population of the non-target species, in some cases on a relatively large scale. The biological features of the population are generally disrupted from what they were previously, and this disruption is presumed to be outside the intentions of society, by the definition of the term, "non-target species."

The long-term effects of chemical pesticides on non-target species are unpredictable, and some evidence indicates that they might actually be beneficial** to small groups of the non-target population.

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*Environmental Pollution Panel, President's Science Advisory Committee, D. F. Hornig, Chairman, Restoring the Quality of Our Environment, Superintendant of Documents, November, 1965.

**Holden, A. V., "Effects of Pesticides on Fish," in C. A. Edwards, ed., Environmental Pollution by Pesticides, London, Plenum Press, 1973, p. 239.

Thus, when some fish in a crowded pond or stream are killed by pesticides, the survivors are seen to grow larger. These benefits are thought to be transient, however, and benefits of this type will not be analyzed in detail. The killing of some members of the non-target population, although presumably "weaker" specimens, will be defined as a cost to be borne, usually by society at-large, although sometimes by subgroups within society, such as sportsmen, or wildlife enthusiasts.

The time span over which the costs of the above effects are to be borne is another important factor. The time period of these effects varies with the type of pesticide, and with the non-target species which bears the effects. In the present analysis, these effects are assumed to be gradually cumulative for a period of five years. During this period, residues of pesticides applied are assumed to gradually build up in soil, and in certain species, even though the pesticide ingredients do decay at varying rates as they filter through the environment. Although this accumulation has been shown to have biological limits, no matter how much pesticide is used, for certain pesticides, in certain species,* the present analysis will assume that the level of residue in the entire biomass of a given species will continue to increase gradually over a five-year period. This assumption is more acceptable when the pesticide in question is a new registration, rather than a reregistration.

The overall approach of the environmental submodel is to make many simplifying assumptions in order to achieve a completely integrated cost structure which interconnects the rate of pesticide application with the incremental effects each new amount of a specific pesticide produces. Many of these simplifying assumptions are not justifiable in the light of currently available hydrologic, ecologic, and other models. These sophisticated models typically use large amounts of data and mathematical formulations which are based on sound chemical and biologic theory,** in order to assess in detail all of the factors

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*Edwards, C. A., *Persistent Pesticides in the Environment*, Cleveland, Chemical Rubber Company Press, 1973, p. 95.

**Robinson, J., "Dynamics of Pesticide Residues in the Environment," in C. A. Edwards, ed., *op. cit.*, p. 459; and Crawford, N. H., and A. S. Donigan, Jr., *Pesticide Transport and Runoff Model for Agricultural Lands*, Washington, D. C., Superintendant of Documents, 1973 (EPA-660/2-74-013, Southeast Environmental Research Laboratory, Athens, Georgia).

and phenomena involved in determining the final effects of a certain amount of pesticide application. In the light of these models, and their complexity, the simplifying assumptions included in the present analysis cannot be justified indefinitely. These assumptions are used for the present in order to present an overall benefit-cost structure and to illustrate all of the types of calculations which must be linked together (Exhibit 6.1). But eventually, the complex models referenced, and others, will necessarily be substituted in order to achieve theoretical soundness and much improved accuracy.

6.2 Accumulation and Degradation Processes

The purpose of this component of the environmental submodel is to calculate three variables needed for subsequent assessment of effects on non-target species:

- Amounts of specific pesticides applied per agricultural acre at regional, and if needed, state, levels of detail;
- Decay rates of these pesticides in the soil; and
- Runoff rates, or rates at which these pesticides enter the water.

As noted above, these calculations will be based on simplifying assumptions, and the algorithms presented can be replaced eventually by more complex mathematical models.

One of the simplifying assumptions concerns the fate of pesticides once they have been washed into bodies of water near the agricultural fields. Most of the pesticides used by farmers are non-soluble in water, and the only persistence they have before sinking to the bottom is due to the turbulence of flowing water, or water which is agitated in some other way.*

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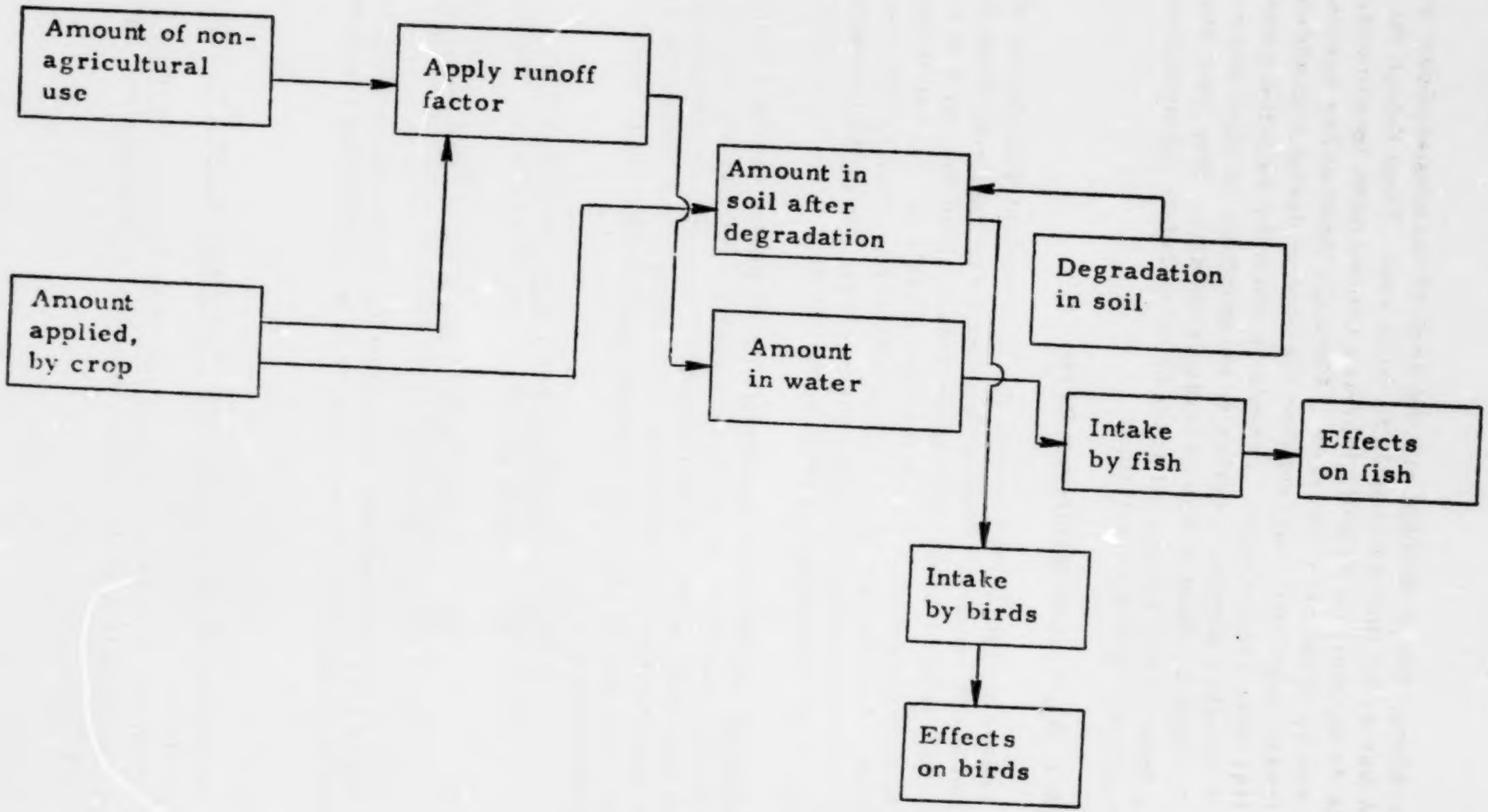
*Edwards, C. A., "Pesticide Residues in Soil and Water," in C. A. Edwards, ed., op. cit., pp. 447 ff.

EXHIBIT 6.1: Calculations Needed for Environmental Effects Submodel


Amount of non-agricultural use
Apply runoff factor
Amount applied, by crop
Amount in soil after degradation
Degradation in soil
Amount in water
Intake by fish
Effects on fish
Intake by birds
Effects on birds

Therefore, the pesticides are not seen to accumulate from year to year in water, as they are known to do in soil. Even though these chemicals do accumulate in soil, they are broken down by microbes in the soil, and by chemical processes. Although these decay processes are not linear, some data suggest that the rate of decay resembles a straight line over some ranges, especially after the half-life point is reached.* In other words, a series of assumptions is used to avoid the use of complex runoff and meteorologic models. The first step in achieving these decay and runoff rates is to calculate the application rate per acre for specific pesticides.

6.2.1 Application Rates Per Acre

A separate algorithm permits the independent calculation of pounds and acres treated, since proportions are available from Eichers, et al.** This type of calculation is desirable since the ratio of pounds applied to acres treated is an important variable in soil and water concentrations. Arbitrary evaluations of this ratio, such as the use of USDA or individual state recommended values, could lead to unreliable estimates of environmental pesticide residues.

Although various data are available on pesticides by groups, there are very few sources of data on specific pesticides used at regional and state levels. The USDA-ERS surveys of 1966 and 1971 are one such source (see Exhibit 6.2 for sample data from the 1966 survey). The data from these surveys provide two kinds of ratios for each of two years:

$$d_{ij} = \frac{P_{ij}}{P_i} = \frac{\text{pounds of pesticide i used in region j}}{\text{total pounds of pesticide i in all regions}}$$

and:

$$c_{ij} = \frac{a_{ij}}{a} \quad \frac{\text{acres treated in region j by pesticide i}}{\text{all acres treated in region j by all pesticides}}$$

Thus, d_{ij} is a ratio of pounds for a specific pesticide, and c_{ij} is a ratio of acres for a specific region. The reason for defining these ratios as

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*Edwards, C. A., Persistent Pesticides in the Environment, op. cit., p. 16.

**Eichers, T., et al., Quantities of Pesticides Used by Farmers in 1966, Washington, D.C., Superintendent of Documents, ERS No. 179, April, 1970.

they are defined above is to enable the use of existing data on production of a given pesticide by disaggregating these data for specific pesticides and regions.

For example, the data from the Pesticide Review on pounds of pesticides produced is available for specific products, but not for states and regions (see Exhibit 6.3). Multiplying the total national amount of a specific pesticide sold for agricultural use by the factor d_{ij} will give the amount of pounds applied in region j. Similarly, the Pesticide Review gives data on the acres of crops treated by pesticides for states and regions (see Exhibit 6.4). Applying the factors c_{ij} to these acreage data will tell how many acres were treated with each specific pesticide. In summary, the required algorithms can be written as summarized in Exhibit 6.5.

For either or both of the two years, of course, the pounds per acre could be obtained more simply from the USDA survey data. The procedure shown in Exhibit 6.5, however, enables the forecast of pesticides in proportion to each other. Before applying the proportions for pounds (d_{ij}), it is necessary to ensure that total pounds are agricultural data. Ajustments such as those shown in Exhibit 6.6 may be needed.

6.2.2 Decay Rates in Soil

The algorithm for calculating decay rates in soil is shown in Exhibit 6.7. The procedure shown actually calculates the coefficients needed to reduce some amount of pesticides, either pounds per acre, or parts per million, over a multi-year period. These coefficients must be applied annually to the total amount of pesticides for that year, including previous residue and new applications. Although some data exist for historical residue levels,* such levels would be irrelevant for a new pesticide applying for registration. In such a case, estimates of each year's application from Section 6.1 above, or from the parallel chemical technique would be required. Section 6.1 above shows how to estimate pounds applied per acre if production in pounds is known. Manufacturer's forecasts of production amounts would enable the use of this type of estimation.

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*Edwards, C. A., op. cit., Tables 1 and 2, pp. 8 ff.

EXHIBIT 6.2

Table 24.--Quantities of selected herbicides used on crops, by regions, United States, 1966 1/

Type of herbicide product 2/	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
	Pounds of active ingredients										
	1,000 pounds										
Inorganic herbicides	1,074	7	132	126	---	363	251	287	240	838	3,318
Organic herbicides:											
Arsenicals	---	---	17	---	20	70	608	147	---	4	866
Phenoxy:											
2,4-D	721	2,700	9,827	10,376	1,154	302	450	3,590	4,202	6,191	39,513
2,4,5-T	6	145	82	61	38	10	148	148	3	12	653
MCPA	25	326	147	855	2	49	---	96	98	14	1,612
Other phenoxy	4	3	15	6	5	240	3	---	837	344	1,457
Total phenoxy	756	3,174	10,071	11,298	1,199	601	601	3,834	5,140	6,561	43,235
Phenyl urea:											
Diuron	87	4	22	---	70	104	513	254	36	534	1,624
Linuron	694	336	252	16	20	32	75	---	---	---	1,425
Other phenyl urea	18	16	23	---	62	282	90	38	1	114	644
Total phenyl urea	799	356	297	16	152	418	678	292	37	648	3,693
Amides:											
Propachlor	---	318	1,895	52	---	---	4	---	---	---	2,269
Propanil	---	---	---	---	---	---	1,453	1,136	---	---	2,589
NPA	6	49	690	3	110	3	138	---	---	---	999
Total amides	6	367	2,585	55	110	3	1,595	1,136	---	---	5,857
Carbamates:											
CIPC and IPC	72	21	293	1	6	1	79	---	17	663	1,153
CDAA	36	1,042	3,688	132	---	---	---	---	---	---	4,898
Other carbamates	19	703	666	191	407	502	90	---	353	1,045	3,976
Total carbamates	127	1,766	4,647	324	413	503	169	---	370	1,708	10,027
Dinitro group	903	8	348	91	194	1,276	4	66	26	2,046	4,962

EXHIBIT 6.2 (continued)

Table 24.--Quantities of selected herbicides used on crops, by regions, United States, 1966 [1]--Continued

Type of herbicide product [2]	Pounds of active ingredients										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	1,000 pounds										
Triazines:											
Atrazine	2,289	4,722	9,978	2,285	2,492	519	157	334	97	622	23,495
Propazine	---	---	---	14	---	---	31	530	5	---	580
Other triazines	12	8	160	---	7	---	[3]	---	---	6	193
Total triazines	2,301	4,730	10,138	2,299	2,499	519	188	864	102	628	24,268
Benzoic:											
2,3,6-TBA	---	155	2,590	137	---	---	---	---	2	54	2,938
Amiben	---	463	3,101	140	32	3	26	---	---	---	3,765
Dicamba	---	5	37	54	---	[3]	---	---	57	69	222
Total benzoics	---	623	5,728	331	32	3	26	---	59	123	6,925
Other organics:											
Trifluralin	50	148	988	58	499	814	1,634	572	147	274	5,184
Others	194	409	529	279	127	363	352	349	183	1,300	4,065
Total other organics	244	557	1,517	337	626	1,177	1,986	921	330	1,574	9,269
Total organic herbicides (not including petroleum)	5,136	11,581	35,348	14,751	5,245	4,570	5,855	7,260	6,064	13,292	109,102
Total herbicides (not including petroleum)	6,210	11,588	35,480	14,877	5,245	4,933	6,106	7,547	6,304	14,130	112,420
Petroleum	3,208	2,468	643	---	765	25,820	2,278	3,279	786	28,386	67,233
Total herbicides (including petroleum)	9,418	14,056	36,123	14,877	6,010	30,753	8,384	10,826	7,090	42,516	180,053

[1] Does not include Alaska and Hawaii.
[2] May include use for purposes other than as herbicides.
[3] Less than 500 pounds.

EXHIBIT 6.2 (continued)

Table 26.--Acres of specified crops treated with selected herbicides, United States, 1966 1/

Type of herbicide product 2/	Acres treated										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	1,000 acres										
Inorganic herbicides	179	6	57	56	---	285	116	93	35	294	1,121
Organic herbicides:											
Arsenicals	---	---	30	---	15	110	614	215	---	101	1,085
Phenoxy:											
2,4-D	898	5,274	14,592	19,116	1,609	304	520	2,417	7,664	4,499	56,893
2,4,5-T	69	63	426	120	76	20	213	534	22	24	1,565
MCPA	38	855	216	1,552	2	26	---	124	82	16	2,911
Other phenoxy	10	35	74	701	21	54	26	---	140	34	1,095
Phenyl urea:											
Diuron	57	4	43	---	203	149	773	312	14	273	1,828
Linuron	95	457	412	22	24	35	219	---	---	---	1,264
Other phenyl urea	33	1	28	---	78	56	153	48	3	26	426
Amides:											
Propachlor	---	181	1,362	86	---	---	3	---	---	---	1,632
Propanil	---	---	---	---	---	---	462	473	---	---	935
NPA	5	36	552	38	159	6	125	---	---	---	921
Carbamates:											
CIPC and IPC	9	32	360	2	43	6	115	---	3	165	735
CDAA	6	711	2,910	94	---	---	---	---	---	---	3,721
Other carbamates	6	312	149	171	191	198	51	---	281	746	2,105
Dinitro group	237	109	92	192	159	295	10	91	34	292	1,511

See footnotes at end of table.

EXHIBIT 6.2 (continued)

Table 26.--Acres of specified crops treated with selected herbicides, United States, 1966 1/--Continued

Type of herbicide product 2/	Acres treated										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	1,000 acres										
Triazines:											
Atrazine	1,316	3,139	6,224	1,771	1,543	350	142	174	71	248	14,978
Propazine	---	---	---	11	---	---	19	412	5	---	447
Other triazines	14	15	71	---	17	---	6	---	---	7	130
Benzoic:											
2,3,6-TBA	---	80	1,380	103	---	---	---	---	3/	64	1,627
Amiben	---	445	3,372	202	41	2	24	---	---	---	4,086
Dicamba	---	55	80	488	---	19	---	---	424	567	1,633
Other organics:											
Trifluralin	79	159	1,073	90	886	947	2,207	989	240	283	6,953
Others	66	328	384	192	120	327	255	250	88	189	2,199
Petroleum	93	105	109	---	82	3/	80	90	37	58	654

1/ Does not include Alaska and Hawaii.
2/ May include use for purposes other than as herbicides.
3/ Less than 500 acres.

EXHIBIT 6.2 (continued)

Table 29.--Quantities of selected types of insecticides used on crops, by regions, United States, 1966 1/

Type of insecticide product 2/	Pounds of active ingredients										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	1,000 pounds										
Inorganic insecticides	2,367	668	915	4	1,027	729	---	---	---	63	5,773
Botanicals and biologicals	2	---	1	---	3/	3	---	3/	3/	36	42
Synthetic organic insecticides:											
Organochlorines:											
Lindane	45	58	18	1	2	169	3/	53	40	9	395
Strobane	---	---	---	---	9	46	1,961	---	---	---	2,016
TDE (DDD)	189	108	198	3	1,145	723	40	347	13	88	2,854
DDT	734	430	361	39	1,837	10,850	7,120	2,702	1,188	1,060	26,321
Methoxychlor	381	5	48	3/	249	200	6	---	163	4	1,056
Endrin	5	---	---	---	194	67	435	34	3/	---	735
Heptachlor	1	48	1,412	14	7	14	13	1	3	3/	1,513
Dieldrin	43	97	39	4	23	260	1	164	62	11	704
Aldrin	30	717	12,973	416	333	79	14	18	110	61	14,751
Chlordane	13	154	119	---	11	74	22	---	41	18	452
Endosulfan	94	32	28	---	7	56	---	28	56	487	788
Toxaphene	4	111	403	7	2,521	13,740	7,176	4,982	1,420	560	30,924
Others	3	1	---	---	20	48	52	---	---	146	270
Total organochlorines	1,542	1,761	15,599	484	6,358	26,326	16,840	8,329	3,096	2,444	82,779
Organophosphorus:											
Disulfoton	100	293	350	429	368	11	11	24	298	60	1,944
Bidrin	---	---	---	---	8	7	220	713	878	31	1,857
Methyl parathion	1	---	74	2	416	2,224	3,090	1,949	41	194	7,991
Parathion	287	235	690	1,350	356	1,177	263	2,237	298	1,544	8,437
Malathion	386	26	143	54	618	323	474	188	1,199	875	4,286
Diazinon	91	610	1,836	1,496	298	19	149	---	43	1,019	5,561
Trichlorfon	2	---	---	1	4	---	11	205	717	54	994
Azinphosmethyl	575	142	82	---	127	24	22	7	91	403	1,473
Ethion	24	7	329	9	2	1,153	73	20	18	369	2,004
Others	176	93	64	49	113	381	21	16	166	952	2,031
Total organophosphorus	1,642	1,406	3,568	3,390	2,310	5,319	4,334	5,359	3,749	5,501	36,578

EXHIBIT 6.2 (continued)

Table 29.--Quantities of selected types of insecticides used on crops, by regions, United States, 1966 1/--Continued

Type of insecticide product 2/	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	Pounds of active ingredients										
	1,000 pounds										
Carbamates:											
Carbaryl	1,384	705	1,283	302	1,055	3,033	633	2,293	56	1,096	11,840
Others	47	51	79	322	---	24	---	---	8	---	531
Total carbamates	1,431	756	1,362	624	1,055	3,057	633	2,293	64	1,096	12,371
Other synthetic organics	---	---	12	---	---	---	---	---	---	11	23
Total synthetic organics	4,615	3,923	20,541	4,498	9,723	34,702	21,807	15,981	6,909	9,052	131,751
Total insecticides (not including petroleum)	6,984	4,591	21,457	4,502	10,750	35,434	21,807	15,981	6,909	9,151	137,566
Petroleum	1,922	6	23	---	489	6,879	618	43	---	1,177	11,157
Total insecticides	8,906	4,597	21,480	4,502	11,239	42,313	22,425	16,024	6,909	10,328	148,753

1/ Does not include Alaska and Hawaii.
2/ May include use for purposes other than as insecticides.
3/ Less than 500 pounds.

EXHIBIT 6.2 (continued)

Table 31.--Acres of all crops treated with selected insecticides, by regions, United States, 1966 1/

Type of insecticide product 2/	Acres treated										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
	1,000 acres										
Inorganic insecticides	129	89	55	3/	79	105	---	---	---	6	463
Botanicals and biologicals	10	---	24	---	1	1	---	5	1	92	134
Synthetic organic insecticides:											
Organochlorines:											
Lindane	64	132	216	40	17	239	7	164	28	15	922
Strobane	---	---	---	---	3	39	183	---	---	---	225
TDE (DDD)	82	29	35	3	476	171	7	8	4	24	839
DDT	315	223	360	81	766	2,360	1,785	1,206	480	481	8,057
Methoxychlor	402	3	45	1	212	84	26	---	154	1	928
Endrin	12	---	---	---	47	31	358	71	3	---	522
Heptachlor	21	150	1,713	135	3	14	43	6	11	2	2,103
Dieldrin	57	61	137	22	98	81	6	132	122	14	730
Aldrin	16	832	11,914	402	345	61	26	13	140	72	13,821
Chlordane	13	116	104	---	14	119	43	---	36	27	472
Endosulfan	92	22	25	---	7	85	---	4	25	292	552
Toxaphene	2	13	307	8	544	1,553	1,233	1,304	217	202	5,383
Others	7	12	---	---	9	90	90	---	---	267	475
Organophosphorus:											
Disulfoton	106	138	339	405	433	11	38	217	245	76	2,008
Bidrin	---	---	---	---	43	61	368	714	143	99	1,428
Methyl parathion	1	---	9	7	179	898	1,949	1,185	115	168	4,511
Parathion	407	269	910	1,115	295	454	191	1,389	416	694	6,140
Malathion	285	13	151	81	285	176	173	267	420	379	2,230
Diazinon	226	615	1,824	1,510	369	31	50	---	99	429	5,153
Trichlorfon	1	---	---	4	9	---	27	206	275	14	536
Azinphosmethyl	426	141	51	---	98	43	28	14	66	323	1,190
Ethion	31	13	130	10	1	470	26	5	20	183	889
Others	203	49	90	49	95	224	117	38	156	1,118	2,139
Carbamates:											
Carbaryl	541	178	298	181	516	780	175	579	53	449	3,750
Others	64	92	151	775	---	23	---	---	5	---	1,110
Other synthetic organics	---	---	3/	---	---	---	---	---	---	33	33
Petroleum	70	12	10	---	115	172	56	3/	---	32	467

1/ Does not include Alaska and Hawaii. 2/ May include use for purposes other than as insecticides. 3/ Less than 500 pounds.

Source: Eichers, T., et al., Quantities of Pesticides Used by Farmers in 1966, Agricultural Economic Report No. 179, USDA, ERS, 1970.

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EXHIBIT 6.3

Table 2.--Pesticidal chemicals: Production by classes, United States, 1967-72

Pesticide	1967	1968	1969	1970	1971	1972 1/
	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds	1,000 pounds
Fungicides						
Copper naphthenate	3,473	1,718	1,545	1,730	1,695	2,206
Copper sulfate 2/	33,992	37,192	42,072	28,768	31,112	28,064
Dithiocarbamic acid salts	3/	3/	3/	39,381	35,110	40,438
Ferbam	2,331	1,900	1,500 4/	3/	3/	3/
Nabam	1,361	2,000 4/	1,938	3/	3/	3/
Zineb	3,055	3,081	2,500 4/	3/	3/	3/
Mercury fungicides	912	1,448	941	1,114	601	347
Pentachlorophenol (PCP) 5/	44,239	48,575	45,988	47,170	50,877	49,704
2,4,5-Trichlorophenol and salts	25,254	28,066	3/	3/	3/	3/
Other organic fungicides	63,269	66,793	85,607	50,307	60,875	49,610
Total 6/	177,886	190,773	182,091	168,470	180,270	170,569
Herbicides						
2,4-D acid 7/	(77,139)	(79,263)	(47,077)	(43,576)	3/	3/
2,4-D acid, esters, and salts	83,750	94,116	56,998	3/	3/	3/
DNBP, ammonium salts	58	3/	3/	3/	3/	3/
Maleic hydrazide	3/	3/	2,771	3,271	3/	4,472
Methanearsonic acid salts	3/	3/	3/	30,454	24,476	30,698
Phenyl mercuric acetate (PMA) 8/	518	582	536	457	337	307
Silvex	3/	3/	1,597	2,016	3/	3/
Sodium chlorate 9/	30,000	30,000	30,000	30,000	30,000	30,000
2,4,5-T acid 7/	(14,552)	(17,530)	(4,999)	3/	3/	3/
2,4,5-T acid, esters, and salts	27,189	42,542	11,626	12,835	3/	3/
Other organic herbicides	206,759	235,541	268,238	312,132	404,036	416,141
Total	439,965	499,574 10/	423,840	434,241	458,849	481,618
Insecticides, fumigants, rodenticides 11/						
Aldrin-toxaphene group 12/	120,163	115,974	107,311	88,641	116,264	141.858
Calcium arsenate	2,040	3,398	1,158	1,144	940	3/
DDT	103,411	139,401	123,103	59,316	3/	3/
Dibromochloropropane	5,240	7,887	8,611	3/	3/	3/
Lead arsenate	5,952	9,016	9,204	4,156	6,168	5,582
Methyl bromide 13/	19,665	20,454	20,033	21,047	3/	24,633
Organophosphorus insecticides 7/	3/	3/	3/	(132,496)	(138,185)	(160,642)
Methyl parathion	33,344	38,163	50,572	41,353	37,226	51,076
Parathion	11,361	20,000 4/	3/	15,259	3/	3/
Other	3/	3/	3/	75,884	100,959	109,566
Other organic insecticides	202,600	227,326	260,892	188,632	303,261	236,442
Total	503,796	581,619	580,884	495,532	564,818	569,157
Grand total	1,121,647 10/	1,271,966 10/	1,186,815 10/	1,098.143 10/	1,203,937	1,221,344

1/ Preliminary.
2/ Shipments by producers to agriculture (including for use as a minor plant nutrient).
3/ Withheld to avoid disclosure. Figure included in totals.
4/ Estimated.
5/ Not only a wood preservative for wood rot control but also a herbicide and desiccant.
6/ Sulfur not included may amount to 150 million pounds.
7/ Figures in parentheses represent duplication but are included in totals to be comparable with the 1971 and 1972 totals.
8/ Also a fungicide.
9/ Estimated shipments to producers of herbicides and defoliants.
10/ Revised.
11/ Includes a small quantity of synthetic soil conditioners; does not include the fumigants carbon tetrachloride, carbon disulfide, ethylene dibromide, and ethylene dichloride, which have many other uses; nor does it include paradichlorobenzene (classed by the Tariff Commission as an intermediate) or inorganic rodenticides.
12/ Includes aldrin, chlordane, dieldrin, endrin, heptachlor, Strobane(R), and toxaphene.
13/ Fumigant for control of both insects and weeds.

Tariff Commission, Bureau of the Census, Bureau of Mines, and chemical industry.

Source: Fowler, D. L., and J. Mahan (eds.), Pesticide Review, 1973, Washington, D.C., USDA, Agriculture Stabilization and Conservation Service, 1974.

109<

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EXHIBIT 6.4

Table 13.--Pesticides used in crops and on livestock and poultry: Acreages treated and cost of treatment by States, United States, 1959

State	Insect control					Nematode control		Fungus control		Weed control				Plant defoliation or Desiccation	
	Hay		Other crops		Livestock and poultry					Pasture		Other crops			
	Acres	Dollars	Acres	Dollars	Dollars	Acres	Dollars	Acres	Dollars	Acres	Dollars	Acres	Dollars	Acres	Dollars
Alabama	17,799	80,527	720,131	5,879,232	421,335	26,781	235,363	47,577	421,150	44,234	93,420	709,179	4,432,243	174,411	565,763
Alaska			342	4,274	1,372			1	170			1,970	8,454		
Arizona	42,160	153,911	519,240	11,624,809	157,210	21,571	275,835	35,934	247,580	12,513	66,391	324,537	2,558,941	202,512	1,758,535
Arkansas	18,571	51,745	[illegible]	8,570,152	435,231	27,937	185,830	41,949	305,525	84,379	157,851	2,575,415	15,532,920	591,739	1,522,752
California	379,[illegible]	2,497,[illegible]	[illegible]	53,11[illegible],339	1,23[illegible],875	245,604	4,737,395	577,[illegible]	11,737,235	56,341	153,187	2,241,848	13,537,175	530,483	[illegible]
Colorado	55,553	240,720	[illegible]	2,444,713	409,942	19,[illegible]	445,333	35,711	241,977	47,[illegible]	105,451	373,747	2,515,198	11,553	57,543
Connecticut	1,531	7,313	[illegible]	523,179	40,774	941	52,153	8,238	291,114	1,737	4,735	42,553	348,595	1,577	[illegible]
Delaware	553	3,001	49,397	440,[illegible]	25,437	1,013	17,083	7,578	[illegible]	350	1,408	187,795	721,762	3,345	[illegible]
Florida	11,742	40,[illegible]	1,257,45[illegible]	23,47[illegible],181	[illegible]	51,4[illegible]	1,213,[illegible]	819,445	13,6[illegible],100	68,166	188,650	476,906	4,080,045	19,745	183,505
Georgia	8,295	67,[illegible]	[illegible]	13,04[illegible]	62[illegible],193	52,832	[illegible]	101,533	1,4[illegible],513	45,917	118,446	852,476	6,250,363	231,[illegible]	1,317,[illegible]
Hawaii	5	2,310	[illegible]	348,133	33,[illegible]	15,126	[illegible]	6,3[illegible]	[illegible]	23,885	254,433	237,983	5,736,790	23,325	[illegible]
Idaho	52,180	187,080	[illegible]	2,930,129	359,152	9,442	159,063	74,252	[illegible]	55,209	147,[illegible]	937,727	3,475,413	55,732	323,[illegible]
Illinois	32,357	150,012	[illegible]	12,74[illegible],347	1,257,478	58,174	247,237	33,390	750,227	55,2[illegible]	181,775	9,222,54[illegible]	40,337,142	58,525	[illegible]
Indiana	52,717	[illegible]	[illegible]	3,[illegible],345	67[illegible],055	18,878	149,323	59,257	[illegible]	33,431	115,921	4,330,895	18,383,113	31,755	183,[illegible]
Iowa	36,465	153,526	[illegible]	[illegible]	2,310,231	44,[illegible]	191,777	74,320	362,575	217,523	423,817	7,547,716	32,[illegible]	72,324	373,135
Kansas	34,772	111,334	1,417,715	3,833,706	[illegible]	[illegible]	55,739	49,[illegible]	[illegible]	454,472	[illegible]	2,[illegible],429	8,[illegible]	31,134	35,329
Kentucky	44,225	187,[illegible]	[illegible]	2,03[illegible],318	673,801	4,415	38,782	[illegible]	115,842	[illegible]	[illegible]	[illegible],717	2,772,347	23,375	[illegible]
Louisiana	22,[illegible]	79,730	[illegible]	8,148,34[illegible]	379,151	[illegible]	100,027	33,415	[illegible]	117,[illegible]	274,338	1,[illegible],539	[illegible]	234,634	715,776
Maine	909	4,314	157,1[illegible]	1,335,[illegible]	77,[illegible]	991	6,616	74,933	[illegible]	840	4,931	124,409	501,187	65,347	354,707
Maryland	16,5[illegible]	51,379	[illegible]	[illegible]	131,307	1,394	27,5[illegible]	26,135	381,308	8,377	21,425	44[illegible],158	1,334,598	4,553	31,793
Massachusetts	1,171	5,751	34,575	808,698	52,852	953	51,179	12,400	295,552	735	2,387	35,252	435,217	3,287	35,325
Michigan	81,715	273,695	454,272	5,863,172	432,132	11,275	204,728	157,033	3,1[illegible]	6,240	33,015	1,835,441	9,335,935	34,790	237,[illegible]
Minnesota	18,152	61,523	1,128,935	3,533,674	775,473	25,169	100,091	97,511	442,325	53,133	103,939	5,502,201	29,450,717	95,371	340,[illegible]
Mississippi	9,283	35,907	1,459,[illegible]	15,573,260	453,180	14,449	106,392	61,814	317,701	85,594	174,433	2,077,770	15,385,801	775,585	2,554,[illegible]
Missouri	39,0[illegible]	139,323	1,149,3[illegible]	4,070,535	1,135,728	17,930	95,211	42,760	445,067	125,[illegible]	377,913	3,241,383	15,852,375	113,832	443,332
Montana	56,009	114,557	98,517	175,776	314,150	1,379	19,242	168,237	177,468	85,872	175,534	2,393,473	2,719,735	13,571	40,561
Nebraska	33,3[illegible]	124,204	2,363,[illegible]	6,483,571	1,358,401	48,514	273,145	50,751	163,[illegible]	387,004	573,122	3,512,416	10,443,427	34,170	87,745
Nevada	63,351	220,743	25,765	201,062	53,072	241	9,984	1,504	8,058	4,505	9,442	18,353	47,558	13,314	30,[illegible]
New Hampshire	354	1,391	7,272	158,912	22,040	14	404	4,340	140,110	271	717	12,[illegible]	77,570	1,249	13,353
New Jersey	4,937	17,932	120,773	2,510,451	85,433	3,889	155,154	50,015	1,055,543	587	3,072	153,007	1,055,215	5,300	61,755
New Mexico	32,534	130,059	215,[illegible]	1,411,428	187,845	9,825	89,335	11,491	74,737	56,512	92,543	[illegible]	728,859	8,535	34,427
New York	125,171	474,737	335,[illegible]	7,073,409	576,576	5,290	145,594	113,279	2,693,275	5,380	29,574	750,443	4,423,384	39,530	217,[illegible]
North Carolina	7,553	42,555	823,331	9,345,182	520,877	177,190	2,515,440	39,948	752,143	15,[illegible]	54,479	927,432	5,532,431	125,[illegible]	1,134,335
North Dakota	33,073	39,072	337,574	604,777	369,365	16,465	155,322	213,734	306,581	62,378	101,499	6,817,732	5,865,523	145,[illegible]	255,393
Ohio	140,536	412,349	654,556	3,437,522	544,619	15,391	113,879	79,734	1,393,54[illegible]	19,812	75,103	2,715,659	10,356,505	22,279	140,529
Oklahoma	85,317	235,281	502,239	2,029,445	828,586	18,050	136,250	34,201	225,973	381,430	769,518	513,731	1,587,344	47,593	153,[illegible]
Oregon	36,358	137,427	223,177	3,734,313	230,030	17,853	509,880	111,523	1,456,29[illegible]	115,729	187,568	1,39[illegible],834	4,253,888	31,912	200,270
Pennsylvania	145,400	485,033	217,125	3,250,381	558,245	4,311	74,832	79,901	1,553,474	10,132	31,567	723,545	3,290,747	24,730	1[illegible]5,423
Rhode Island	37	372	7,555	175,423	3,841	8	245	2,899	58,367	92	255	[illegible],347	65,358	577	2,094
South Carolina	15,741	23,330	714,757	8,246,454	200,441	61,382	525,235	36,159	659,245	25,542	53,322	571,634	3,137,833	150,504	641,213
South Dakota	47,358	88,239	459,730	994,025	581,827	11,009	35,784	20,278	29,769	113,298	153,755	3,129,915	3,9[illegible],920	28,840	53,757
Tennessee	14,219	61,610	348,774	1,846,839	454,329	12,125	105,[illegible]	16,925	153,447	25,540	90,853	88[illegible],385	4,358,433	61,455	255,25[illegible]
Texas	122,301	385,774	4,233,453	22,029,166	2,556,182	85,191	673,048	240,092	2,415,333	1,714,842	2,712,378	5,257,438	20,900,056	1,434,341	3,913,[illegible]
Utah	95,749	290,387	25,[illegible]	223,591	121,557	5,649	159,620	7,132	64,327	11,353	19,124	139,007	288,775	3,228	22,[illegible]
Vermont	7,430	25,589	11,399	173,418	81,311	389	2,797	3,750	117,485	722	4,352	39,441	234,550	2,123	14,484
Virginia	29,735	78,650	272,144	3,081,166	313,193	59,277	575,066	55,952	1,328,944	121,526	294,050	503,588	3,247,746	23,117	233,241
Washington	32,355	155,079	421,834	8,203,409	252,551	15,297	398,631	98,919	1,751,878	25,879	94,037	2,051,774	5,776,290	79,750	500,345
West Virginia	5,592	19,571	21,813	434,080	62,946	329	4,863	15,551	425,445	17,165	43,621	34,517	175,124	5,184	33,930
Wisconsin	18,564	81,505	[illegible]	3,438,076	1,332,347	12,945	57,773	69,328	772,767	43,635	87,358	1,955,8[illegible]	9,258,339	38,143	155,939
Wyoming	35,750	85,735	16,112	63,874	212,725	4,193	132,075	6,395	29,732	79,175	148,538	123,418	644,539	2,7[illegible]	3,337
Total	2,180,223	8,527,705	39,581,556	276,971,125	25,428,158	1,267,101	17,334,850	4,388,033	54,503,095	4,967,459	9,678,727	34,713,547	345,683,739	5,780,391	23,375,345

1/ The "1959 Census of Agriculture".

Source: Fowler, D. L., and J. Mahan (eds.), Pesticide Review, 1972, Washington, D.C., USDA, 1973.

316<

EXHIBIT 6.5: Algorithms for Pounds Per Acre

(1) $PD_{ij} = d_{ij} PD_i$

where:

PD_{ij} = pounds of pesticide i sold in region j

$$d_{ij} = \frac{\text{pounds of pesticide i applied in region j}}{\text{pounds of pesticide i applied nationally}}$$

PD_i = pounds of pesticide i sold nationally (from Exhibit 6.3)

(2) $AC_{ij} = c_{ij} AC_j$

where:

AC_{ij} = acres treated in region j by pesticide i

$$c_{ij} = \frac{\text{acres in region j treated by pesticide i}}{\text{total acres treated in region j}}$$

AC_j = total acres treated in region j (from Exhibit 6.4)

(3) $PA_{ij} = PD_{ij}/AC_{ij}$

where:

PA_{ij} = pounds of pesticide i applied per acre in region j

PD_{ij} = pounds of pesticide i sold in region j

AC_{ij} = acres treated in region j by pesticide i

EXHIBIT 6.6: Calculation of Average Application Rates for Insecticides

Production — exports + imports = application in pounds

Example using 1969 data for United States:

1,134,239,000 — 250,539,492 + 820,288 = 885,019,796

Data source: Fowler, D. L., and J. Mahan, The Pesticide Review, 1972, Washington, D.C., U. S. Department of Agriculture, June, 1973, Table 3.

Proportion used for agriculture = 0.42500 in 1964
= 0.813 in 1973

Example: (.813) (885,019,796) = 719,521,094 pounds

0.4250 from F. Matsumura, "Current Pesticide Situation in the United States," in F. Matsumura, ed., Environmental Toxicology of Pesticides, New York, Academic Press, 1972, p. 38.

0.813 from Rosmarie von Rumker, et al., Production, Distribution,Use and Environmental Impact Potential of Selected Pesticides, EPA-OPP 540/1-74-001, 1974, Table I, p. 7.

acres (1969) = 43,328,890 (see Exhibit 6.4 above, and use total acres for insect and nematode control)

$$\frac{719,521,094}{43,328,890} = 16.6060$$

pounds/acre of insecticides, United States average

EXHIBIT 6.7: Procedure for Calculating Degradation Rates for Pesticides in Soil

1. The purpose of the procedure is to calculate time periods during which certain percentages of pesticides will have disappeared.

   The percentages of interest are 25, 50, and 85.

2. The sources are:

   Edwards, C. A., Persistent Pesticides in the Environment, Cleveland, Chemical Rubber Company Press, 1973, Table 3, Figure 6, p. 16.

   Hurtig, H., "Long-Distance Transport of Pesticides," in F. Matsumura, ed., Environmental Toxicology of Pesticides, New York, Academic Press, 1972, pp. 260-261.

3. Basically, Hurtig gives 75-100 percent loss times for 29 specific pesticides and six groups. Edwards gives half-lives and 95 percent loss times for eight pesticides.

4a. Assume that Hurtig's 75-100 percent loss times are equivalent to Edward's 95 percent loss times (i.e., intervals after application).

4b. Assume that the major source of pesticides in soil is from agricultural applications; other sources are highly localized and will be ignored.

5. Calculate ratio between 95 percent loss time and half-life for eight pesticides given by Edwards:

	Ratio of Half-Life to 95% Loss Time
Aldrin	0.10000
Chlordane	0.25000
DDT	0.28000
Dieldrin	0.31250
Endrin	0.31429
Heptachlor	0.22857
Lindane	0.18462
Isobenzan	0.10000

Average = 0.22125

EXHIBIT 6.7 (continued)

6. Apply average ratio from Step 5 to Hurtig data (75-100 percent intervals) to obtain half-lives (given in years)

Pesticide	75-100% Level (Assume 85%)	Half-Life	25% Interval***
DDT	10*	2.8*	0.933
Aldrin	3*	0.3*	0.100
Toxaphene (same as dieldrin)*	8*	2.5*	0.833
2,4,5-T	0.42**	0.093****	0.031
MCPA	0.25**	0.055****	0.018
2,4-D	0.09**	0.020****	0.007

Note: To linearly interpolate percent losses (x percent) for an arbitrary interval, e.g., two years, use:

$$\frac{\text{(Arbitrary interval) - Interval 1}}{\text{Interval 2 - Interval 1}} = \frac{\text{x\% - percent 1}}{\text{percent 2 - percent 1}}$$

*See Edwards, 1973, p. 16.

**Hurtig, p. 261.

***Apply arbitrary rule of one-third half-life.

****Apply average ratio of half-life to 95 percent loss time determined in Step 5, i.e., use factor of 0.22125. (This calculation assumes that the relationship between half-life and 95 percent loss time is the same for both the phenoxy herbicides and the typical chlorinated hydrocarbons listed in Step 5.)

EXHIBIT 6.7 (continued)

7. **Degradation (Persistence) Factors in Soil**

Percent Loss After Time Period*

Pesticide	Months (Years)						
	1 (.08)	6 (0.5)	12 (1)	24 (2)	48 (4)	96 (8)	192 (16)
DDT		13.40		39.29		75.28	95**
Aldrin	20	52.59			95		
Toxaphene			27.50		59.55	85	95
2,4,5-T	44.76	85	95				
MCPA	54.49	85	95				
2,4-D	85	95					

*Percents between 25, 50, 85 percent decay points are linearly interpolated.

**If number of months is greater than 85 percent interval, arbitrarily assign 95 percent.

6.2.3 Runoff Rates

Before calculating the amount of pesticide which decays in the soil each year, the amount which runs off into adjacent bodies of water should be calculated. This amount should be subtracted from the total residual amount of pesticide remaining from the previous year, plus what has been applied in the current year. Amounts of pesticides in water are available from published sources.* Some examples of these residues are shown in Exhibit 6.8. Since residues in water are relatively transient, it is likely that these amounts are from recent applications, and they can be connected to application rates. A procedure for calculating runoff rates from application rates is shown in Exhibit 6.9.

It should be understood that the algorithms presented above are extreme short-cut methods for calculating a few basic physical variables so that the overall benefit-cost system will be integrated, and so that the benefits and costs which are finally obtained will have at least a minimal basis in the physical phenomena which govern the distribution of pesticides.

6.3 Biological Uptake

Before proceeding to the biological uptake algorithms, it is possible to summarize the residue algorithms described in Section 6.2 above, and to set a standard notation for use in the subsequent equations. In addition to the water residual equations described previously, the equation shown in Exhibit 6.10 contains a factor for estimating pesticide residues which reach bodies of water more directly than by runoff from treated acres, such as from rainfall, dust, and air currents, as well as from spills and dumping. Although this factor is arbitrary, and is based only on the relative number of acres of water in a region, it should serve as a reminder that pesticides do, in fact, reach bodies of water in several different ways. The coefficient used in the calculation of the direct impingement factor suggests that the meteorologic effects would result in a linear decline in pesticides which are blown into water, but the nature of this coefficient should be more accurately estimated from meteorologic data.

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*Edwards, C. A., "Pesticide Residues in Soil and Water," op. cit., pp. 440-441.

EXHIBIT 6.8: Pesticide Residues for Water (numbers are in ng/l)*

Pesticide	Region									
	North-east	Appala-chian	North-ern Plains	Lake States	South-est	Delta States	Corn Belt	South-ern Plains	Moun-tain	Pacific
DDT				135.5 (1971)	33.20 (1971)	416.00 (1966)	9.83 (1968, 1967, 1970)	79.90	11.3 (1966)	
Aldrin						17.5 (1966)			26.39 (1967, 1969)	
Dieldrin				58.55 (1971)		35.00 (1966)	26.17		22.1	

*ng/l is expressed as parts per trillion or 10^{-12}. Therefore, to convert numbers to ppm, multiply by 10^{6}.

EXHIBIT 6.9: Example of Calculating Runoff Factors For One Region (Delta Region = Mississippi, Louisiana, Arkansas)

Pounds per acre should be calculated by the procedure shown in Exhibit 6.5 for the year 1966. In order to simplify this problem, assume pounds per acre is found to be 16.6060, as found in Exhibit 6.6.

Then the concentration in soil = 8.3030 ppm in 1966 (see Exhibit 6.10 below).

The total levels in water = 0.0004685 ppm (see residues for water data).

$$\text{Runoff factor} = \frac{0.0004685}{8.3030} = 0.0000564253$$

or 0.005643 percent for the region, assumed to be a constant over time.

The above calculations illustrate procedures for calculating residues in water based on amounts of insecticides applied.

Data sources:

Pounds per acre = 16.6 from Exhibit 6.6 above.
Level in water = 0.0004685 (sum of three pesticides) from Exhibit 6.8 above.

EXHIBIT 6. 10: Residue Equations

(1) $PLS_{ijk} = PLS_{i(j-1)k} + [(CV)\ (AA_{ijk}/CT_{ijk}) - PLW_{ijk}]\ [100 - DF_{ik}]$

(2) $PLW_{ijk} = [APW_{ijk} + ROF_{ik}]\ [(CV)\ (AA_{ijk}/CT_{ijk})]$

(3) $WTL_{ijkp} = (PLW_{ijk}/LC_{mkp})$

where:

PLS_{ijk} = soil pollution level in region i at time j for pesticide k, in ppm of pesticide in soil,

CV = a constant for converting pounds per acre to ppm:

1/2 pound/acre = ppm.

Source: C. A. Edwards, ed., 1973, p. 413,

AA_{ijk} = amount of pesticide k applied in region i between j-1 and j,

CT_{ijk} = the total acres of land treated by pesticide k in time j and region i,

PLW_{ijk} = water pollution level in region i at time j for pesticide k, in mg/kg, i.e., parts per million of pesticide in water,

DF_{ik} = degradation factor, usually in percent per year, for region i and pesticide k, for soil,

APW_{ijk} = the water application and drift factor in region i at time j for pesticide k, a unitless proportion equal to:

(.01) (acres of water surface in region i) / (acres of land surface in region i)

EXHIBIT 6.10 (continued)

Source: Lerner, W., ed., Statistical Abstract of the United States, Washington, D.C., 1973, U. S. Bureau of the Census, p. 172,

ROF_{ik} = proportion of amount of pesticide k applied which washes off of fields between (j-1) and j, a unitless measure,

WTL_{ijkp} = proportion of existing residue levels in region i at time j to predefined lethal concentration level "m" (usually 50 percent), for organism p and pesticide k. This proportion is a useful indicator in itself, and it is also used implicitly in equation (2), Exhibit 6.12, below.

LC_{mkp} = the lethal concentration of pesticide k that will kill m percent of species p.

Note: Equations (1) and (2) provide a method for calculating accumulated residuals in soil and water if application rates per acre are known. Equation (3) is a preliminary damage indicator.

The biological uptake equations are simple applications of concentration factors described in the literature.(see Exhibit 6.11). Although these concentration factors are usually much greater than one, they may be less than one, i.e., dilution factors, for some organisms and for some pesticides. In the case of fish, these uptake factors are thought to depend on absorption through the gills, but may also involve food chain accumulation. In the case of birds, the source of pesticides is almost entirely through the food chain, and the biological uptake algorithm for birds has been constructed to contain four possible sources of pesticides in birds' diets (invertebrates and plants from soil and water). These factors could be weighted for the species of bird, but for now, they are merely averaged.

6.4 Population Damages

Three kinds of population damages are possible because of the uptake of pesticides: acute (immediate), chronic, and reproductive disruption (see Exhibit 6.12). Data were not available for all types of damage for both birds and fish, because certain types of damages are not readily observed, and may not occur except in rare cases. For example, acute (immediate) toxic effects in birds are rarely observed, perhaps because their mobility enables them to escape the immediate application situation.

Conversely, the chronic toxicity phenomenon is difficult to observe in fish because they are generally extremely fast concentrators of any pesticide which enters the water. Equation (1) in Exhibit 6.12 for fish reproduction disruption was developed based on one study which lasted 156 days. In any case, perhaps these equations represent the types which should eventually be conveniently available to EPA.

One important assumption is that the population for any given year can be reduced by the amount of individual organisms killed by pesticides to obtain the population for the following year. This type of assumption is not necessary to the calculation of actual damages, since the number of birds (fish) killed is the essential piece of information. The equation is necessary to tie the successive years together when not all years are represented by available data. Estimates of actual population sizes are difficult to find in published sources, and substitute variables must be used as a basis for estimating total population. Three such variables are woodcock killed by hunters (see

EXHIBIT 6.11: Biological Uptake Algorithms

A. Fish

$$CFH_{ijkp} = (KF_{jkp})\ (PLW_{ijk})$$

where:

CFH_{ijkp} = concentration of residue in fish type p, region i, time j, pesticide k, in ppm,

KF_{jkp} = concentration factor for fish category p, pesticide k, time j,

$= \dfrac{\text{concentration in fish}}{\text{concentration in water}}$, a unitless proportion.

Source: C. A. Edwards, Persistent Pesticides in the Environment, op. cit., 1973, Table 21, p. 63.

PLW_{ijk} = water pollution level in region i at time j for pesticide k, in ppm,

B. Birds

$$CBD_{ijkp} = (KB_{jkp})\ 1/4\ \left[(K_1\ B_{jk})\ (PLS_{ijk}) + (K_2\ B_{jk})\ (PLW_{ijk}) + (K_3\ B_{jk})\ (PLS_{ijk}) + (K_4 B_{jk})(PLW_{ijk})\right]$$

where:

CBD_{ijkp} = concentration in ppm of pesticide k in bird type p, time j, region i,

KB_{jkp} = concentration of pesticides into birds from diets for bird type p, pesticide k, time j,

PLW_{ijk} = water pollution level in region i at time j for pesticide k, in ppm, EXHIBIT 6. 11 (continued)

Sources:

K_1 B_{jk}	Table 13, Earthworms, Slugs, Anthropods
K_2 B_{jk}	Table 15, Freshwater Invertebrates
K_3 B_{jk}	Table 27, Soil into Water
K_4 B_{jk}	Table 28, Water into Plants

C. A. Edwards, 1973, op. cit., pp. 36 ff.

Note 1: Concentration into mammals has been observed, but concentration factor for muscle tissues has been measured mostly in domestic animals.

Note 2: Although accumulated totals appear to increase in linear proportion to exposure time for fish, there is a "levelling off" phenomenon in mammals. The relationship for birds is unclear, but is probably similar to that for mammals. (Edwards, op. cit., p. 64, p. 95, p. 80)

EXHIBIT 6.12: Population Damages

A. Fish

Note 1: Holden (Edwards (ed.), op. cit., p. 239)* cites studies in which concentration in fish, mg/kg, was 2 mg/kg/week for 22 weeks, or presumably 44 mg/kg of DDT, since no bioassay data are given. After this time, the mortality of fry (brook trout) was about 3.5 percent higher than controls.

Therefore, assume:

104 mg/kg/year would result in loss of 3.5 percent of next year's population.

(1) $FPP_{i(j-1)p} = FPP_{i(j-1)p} - [CFH_{i(j-1)kp}/104] (.035) (FPP_{i(j-1)p})$

where:

FPP_{ijp} = fish population in year j of fish type p, region i

CFH_{ijkp} = concentration of residue in fish type p, region i, year j, pesticide k, in ppm

Note 2: This formula assumes that other effects would result in a population in (j) exactly equal to population in (j-1).

Note 3: The fish concentration variable (CFH) is not needed to calculate immediate toxic effects since data on toxicity are given in "exposure" amounts which are concentrations in water (see Edwards, op. cit., Table 22, p. 66).

(2) $FPP_{ijkp} = FPP_{i(j-1)kp} - [1/2 (PLW_{i(j-1)k})/(LC_{50})] [1/2 \, FPP_{i(j-1)kp}]$

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*Holden, A. V., "Effects of Pesticides on Fish," in Edwards (ed.), op. cit., p. 239.

EXHIBIT 6.12 (continued)

where:

FPP_{ijkp} = fish population in year j of fish type p in region i containing pesticide k

PLW_{ijk} = water pollution level in region i, year j, for pesticide k, in ppm

Note 4: The fish population of any type in any year j equals the previous year's population less the amount killed by residues. The proportion of the residue to the LC_{50} determines the proportion of half the population killed. Assumption: the lethal concentration is linear from 0 to 50 percent. The above function suggests that if the ratio of $PLW/LC_{50} = > 4$, then 100 percent of the population is killed. The 1/2 factor applied to this ratio reduces $\underline{j}$ to 6 months.

B. Birds

Note 1: Immediate toxic effects are not readily measured in birds, except possibly water fowl. These water fowl effects occur only in unusual circumstances such as accidental spills, etc.

$$(3) \quad BPP_{ijp} = BPP_{i(j-1)p} - \frac{m}{100}(BPP_{i(j-1)p}) \times (CBD_{i(j-1)kp}/LD_{mkp})$$

where:

BPP_{ijkp} = bird population in region i, year j

CBD_{ijkp} = concentration of pesticide k in bird type p in region i, in year j, in ppm

LD_{mkp} = lethal dose, of pesticide k which, if accumulated in birds, will kill m percent of the population of type p

Exhibit 6.13), waterfowl hunting activity (see Exhibit 6.14), and fish stocked from fish hatcheries (see Exhibit 6.15).

6.5 Monetary Evaluations

Various concepts and assumptions for assigning dollar values to wildlife are available, including costs associated with maintaining substantial wildlife populations. In the following discussion, this concept will be discussed, and a second type of costs, those paid by sportsmen, will also be considered.

Assume that each year's property acquisition cost is incurred because of expansion and maintenance of game and fish which may not actually be caught or killed on the Federal lands. Also assume that the value of the game or fish killed or caught is equal to the value of a hunter's day spent killing or catching. If the game or fish taken are not replaced, the value of the hunter's day is not maintained and will be lost the following year. Similarly, the value of a camper's day is the value of maintaining the fish, birds, and other wildlife in national parks and forests (see Exhibit 6.16). Finally, assume that campers "experience" about the same number of animals per day that hunters and fishermen take.

6.6 Areas for Future Work

Upon examining the environmental effects submodel presented in this chapter; it becomes evident that many components of the submodel use oversimplified physical models. However, as additional knowledge is gained and as more data become available, further refinements can be made.

In addition, some components of the submodel are missing. More specifically, the submodel addresses the environmental impacts to birds and fish, but does not address similar impacts to plants and mammals. Birds and fish are accepted as indicator species for determination of environmental impacts resulting from pesticide use, whereas effects on plants and larger mammals have not been as frequently observed.

Nevertheless, plants can be affected by the phytotoxicity of the pesticide, and the LD_{50} level for various mammals can provide insights into the pesticide's toxicity to mammals. However, this information alone is not adequate to predict the likely impacts to plants and mammals from application of a particular pesticide. The mobility, persistence, and bioaccumulation of the pesticide are illustrative of additional factors which must be considered.

Therefore, incorporation of these two components -- i.e., plants and mammals -- into the present environmental effects submodel is not a simple procedure. Additional work and research in this area are required to provide the knowledge and data necessary to perform this task.

EXHIBIT 6.13: The 1971-72 Woodcock Wing-Collection Survey

	A	B	C	D	E	F	G	H	J	K	L	M
	Hunting License Holders		Duck Stamp Sales		Woodcock Kill by Duck Stamp Purchasers		License Holders to Stamp Sales Ratio			Percent of Mean	State Kill Index	State Weight Factor
STATE*	1969-70	1970-71	1969-70	1970-71	1969-70	1970-71	1969-70	1970-71	Mean			
Conn.	77,488	85,452	12,889	15,779	19,531	24,312	6.0119	5.4156	5.7137	64.792	14,203	.0313
La.	337,641	348,635	105,274	129,046	111,991	99,385	3.2072	2.7016	2.9544	33.502	35,408	.0781
Maine	202,766	219,373	15,939	18,182	26,786	34,420	12.7214	12.0654	12.3934	140.539	43,009	.0948
Mass.	118,518	123,589	25,630	29,993	33,489	33,410	4.6242	4.1206	4.3724	49.582	16,585	.0366
Mich.	941,025	941,426	101,562	131,404	56,678	80,595	9.2655	7.1644	8.2149	93.156	63,939	.1410
Minn.	356,607	377,384	144,562	173,877	13,840	21,501	2.4667	2.1704	2.3186	26.292	4,646	.0102
N.H.	98,887	97,360	8,938	9,880	13,599	9,876	11.0637	9.8543	10.4590	118.603	13,921	.0307
N.J.	184,527	196,533	32,974	35,002	29,812	29,086	5.5965	5.6149	5.6057	63.568	18,720	.0413
N.Y.	758,512	756,060	98,403	108,582	86,501	77,693	7.7082	6.9630	7.3356	83.184	68,292	.1506
Ohio	540,718	565,896	35,841	43,508	20,300	13,631	15.0866	13.0067	14.0467	159.287	27,024	.0596
Pa.	1,134,316	1,166,634	67,224	81,074	44,641	56,816	16.8737	14.3897	15.6317	177.261	89,922	.1982
Vt.	138,378	148,282	6,317	7,435	5,393	11,885	21.9056	19.9438	20.9247	237.283	20,499	.0452
Wis.	629,445	634,992	122,291	151,524	47,092	94,187	5.1471	4.1907	4.6689	52.944	37,399	.0824

*Thirteen States having substantial woodcock harvests and being adequately represented in wing-collection survey.

$\frac{A}{C} = G$ $\frac{B}{D} = H$ $\frac{G+H}{2} = J$ $\frac{J}{\frac{\Sigma J}{13}} = K$ $K\left(\frac{E+F}{2}\right) = L$ $\frac{L}{\Sigma L} = M$

Source: Clark, E. R., Woodcock Status Report, 1972, Washington, D.C., U. S. Department of Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, No. 169, 1973.

EXHIBIT 6.14: Waterfowl Hunting Activity and Bags of Ducks and Geese in the United States During the 1970 and 1971 Hunting Seasons (Estimates Unadjusted for Response Bias; Totals Include Activity by Junior Hunters)

State and hunting season	Daily duck bag and possession limits	Days in duck season	Number of adult hunters (potential)	Days per adult hunter	Total hunter-days	Seasonal duck bag per adult hunter	Total duck bag	Seasonal goose bag per adult hunter	Total goose bag
United States total:[2]									
1970	--	--	2,390,770	6.65	17,052,000	8.06	20,298,200	0.87	2,151,800
1971	--	--	2,398,350	6.50	16,719,800	7.11	17,903,900	0.71	1,752,400
Percent change			0	- 2	- 2	- 12	- 12	- 18	- 19

[1] Includes regular and all special duck seasons; regulations summarized for regular season only.

[2] Available for states.

Source: Chamberlain, E. B., et al., Waterfowl Status Report, 1972, Washington, D.C., U. S. Government Printing Office, 1972, Bureau of Sport Fisheries and Wildlife Special Scientific Report Series No. 166, Wildlife, U. S. Department of Interior.

EXHIBIT 6.15

TABLE 4. FISH, AND FISH EGGS DISTRIBUTED BY DESCRIPTION OF WATERS STOCKED, FISCAL YEAR 1973

DESCRIPTION OF WATERS AND SPECIES	EGGS NUMBER	EGGS POUNDS	FRY NUMBER	FRY POUNDS	FINGERLINGS NUMBER	FINGERLINGS POUNDS	ADULTS (6 IN. +) NUMBER	ADULTS (6 IN. +) POUNDS	TOTAL NUMBER	TOTAL POUNDS
HATCHERY-FOREIGN:										
LARGEMOUTH BASS	100,050	18			300	2			100,350	20
SMALLMOUTH BASS					10,000	4			10,000	4
STRIPED BASS					8,628	14			8,628	14
RAINBOW TROUT	1,174,368	227							1,174,368	227
BROOK TROUT	1,057,831	160							1,057,831	140
STEELHEAD TROUT	100,628	30							100,628	30
COHO SALMON	2,174,700	1,310							2,174,700	1,310
TOTAL	4,647,577	1,725			18,928	20			4,646,505	1,745
GRAND TOTAL	46,416,620	15,957	78,809,967	1,815	152,714,041	1,586,710	25,547,779	4,760,136	303,488,443	6,364,618

Source: U. S. Department of the Interior, Propagation and Distribution of Fishen from National Fish Hatcheries for the Fiscal Year 1973, Fish Distribution Report 8, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, 1974, p. 27.

EXHIBIT 6.16: Cost of Replacing Wildlife

A. Cost Equations

Cost per camper day = cost per hunter/fisher day
= cost of providing game and fish

(1) $$CCD_{ij} = FC_{ij}/CD_{ij}$$

where:

CCD_{ij} = cost per camper day, state i, year j

FC_{ij} = Federal park expenditures, state i, year j

CD_{ij} = total number of camper days, state i, year j

(2) $$CAN_{ij} = \frac{CCD_{ij}}{2\,(BRK_{ij} + FSC_{ij}) + OWK_{ij} + OWL_{ij}}$$

where:

CAN_{ij} = cost per animal, state i, year j

BRK_{ij} = number of birds killed per hunter day, average, state i, year j

FSC_{ij} = number of fish caught per fisher day, average, state i, year j

OWK_{ij} = number of other wildlife killed, state i, year j

OWL_{ij} = number of other wildlife in survey, state i, year j

B. Data Sources

$$FC_{ij} = \frac{SPAC_{ij}}{\sum_{i=1}^{50} SPAC_{ij}} \quad FC_j$$

EXHIBIT 6. 16 (continued)

where:

FC_j = total Federal expenditures, year j, Tables 332, 333, 334, pp. 203-204, U. S. Bureau of the Census, *Statistical Abstract of the United States*, W. Lerner, ed., 1974, and

$SPAC_{ij}$ = state park acres, state i, year j, Table 341, p. 207.

Alternatively, obtain Federal expenditure for year j by state directly.

CD_{ij} = obtain from Table 334, *Statistical Abstracts, 1974*, and allocate to states as above, or alternatively obtain NP acreage by state

BRK_{ij} = waterfowl statistics (see Exhibit 6. 14) and woodcock statistics (see Exhibit 6. 13)

FSC_{ij} = sport fishing statistics, or derive from Exhibit 6. 15

OWK_{ij} = deer killed, U. S. Department of the Interior, Fish and Wildlife Service, *Federal Aid in Fish and Wildlife Restoration*, Annual Publication

OWL_{ij} = U. S. Department of the Interior, Bureau of Public Lands, *Public Land Statistics*, 1972, p. 88.

C. Alternative Procedure

Use costs of hunting and fishing licenses to calculate value of wild animals, i. e.,

$$\text{cost per bird} = \left[\frac{HLC_{ij}}{NRH_{ij}}\right] \div [BRK_{ij} \times HUD_{ij}]$$

$$\text{cost per fish} = \left[\frac{HFC_{ij}}{NRF_{ij}}\right] \div [FSC_{ij} \times FID_{ij}]$$

EXHIBIT 6. 16 (continued)

where:

HLC_{ij} = total expenditures for hunting licenses, state i, year j, Table 346 Statistical Abtracts, op. cit.

NRH_{ij} = number of hunters, state i, year j, Table 345, Statistical Abstract, op. cit.

HUD_{ij} = average number of hunting days per hunter, state i, year j, Exhibit 6. 14

HFC_{ij} = total expenditure for fishing business, state i, year j, Table 346, Statistical Abstracts, op. cit.

NRF_{ij} = number of sport fishermen, state i, year j, Table 345, Statistical Abstracts, op. cit.

FID_{ij} = average number of fishing days per sport fishermen, state i, year j, sport fishing statistics

7.0 SUMMARY OF THE BENEFIT-COST SYSTEM PROCEDURES

7.1 Criteria for Design of the Benefit-Cost System and Input Requirements

This chapter summarizes the operating characteristics of the pesticide benefit-cost system. The system has been designed to meet three very broad criteria:

- It must provide for the complete explication of all benefits and costs arising from or attendant on pesticide use,
- It must provide for precise connections between incremental use of specific pesticides and increments of benefits and costs, and
- It must operate within the conceptual structure of economic benefit-cost theory.

In addition to these three broad criteria, there were several specific criteria related to the eventual use of the system. These criteria included a requirement for the use of reasonably available data, preferably from the data requirements of the registration process itself or regularly published government sources, and a requirement for a capability of single or multiple year calculations for at least five years into the future. In addition, the system had to be modular, with specific types or categories of benefits and costs separately assessed and depicted.

The system meets the first broad criterion of comprehensiveness by means of a two-dimensional matrix of benefits and costs. Each of the cells of this matrix are not developed by separate algorithms or submodels (an approach which would have required a voluminous and intricately indexed system of repetitive submodels), but the benefits and costs described in each cell of the matrix direct the user to one of three major submodels:

- Food, feed, and fiber production,
- Health effects, and
- Environmental effects.

Within each of these submodels, flexibility is available for the application of specific algorithms according to specific user needs.

The second broad criterion, sensitivity to incremental use of pesticides, is provided by a precise connection of most algorithms to application rates, residual accumulation, or to degradation rates. These connections require that a system user be able to enter the system with an estimate of annual application rates for an agricultural (multi-state) region, but reference data are incorporated to facilitate such estimates. A simple conversion factor is provided for conversion of pounds per acre applied to parts per million in soil, but a more complex model is available for optional use.

The third broad criterion, economic soundness, is met by a separate theoretical section which supports the calculation of benefits to consumers based on an increase in consumers' surplus. The food, feed, and fiber production (agricultural) submodel provides techniques for calculating the benefits to farmers due to increased sales (yields), and for calculating the benefits to consumers due to change in consumers' surplus. The change in consumers' surplus is a function of demand elasticity which is either selected on the basis of theory or estimated from published research.

Although the benefit-cost system user would in most cases be constrained to enter the system through the agricultural submodel in order to obtain food, feed or fiber production benefits and total amounts of pesticide applied, the user may wish to enter the system either at the health effects or at the environmental effects submodels. In order to do this, the user must have estimates of the pounds of active chemical applied per acre per year by region, state, or county, and he must also have the total amount applied, or the total number of acres treated. Other information is also needed, such as the biological uptake rate by various organisms, the toxicity to experimental animals, and the changes in yield per acre for crops on which the pesticide is used. In each submodel where these variables are required, techniques are provided for obtaining them from published sources, or for estimating them.

7.2 Outputs of the Benefit-Cost System

The outputs of each submodel are a series of tables in standard format which enable the comparison of effects, i.e., impacts among the different submodels, as well as within them. These formatted

tables identify the calculation procedure (algorithm) used, the source of inputs to the algorithm (previous tables or published documents) and the relative point in the overall methodology where that particular calculation occurs.

The outputs of major comparative significance include:

- **Value of change in consumers' surplus,**
- **Cost of application and materials for pesticide analyzed,**
- **Incidence and number of acute and chronic injuries in seven human subpopulations, i.e.,**
    - **Pesticide R and D, manufacturing and formulation workers,**
    - **Pesticide transport personnel,**
    - **Field workers and other farm personnel,**
    - **Commercial farm applicator,**
    - **Non-farm professional applicators,**
    - **Household users, and**
    - **Society as a whole.**
- **Deaths of fish and waterfowl, and**
- **Dollar value of deaths of fish and waterfowl based on government expenditures for maintenance and support of these animals.**

Other intermediate variables such as residue levels and crop yield changes are also calculated and similarly formatted.

7.3 Calculation Procedures

The calculation procedures are kept at a simple level and no equation has more than six terms. No regressions or other statistical techniques are required, although probabilistic or hypothesis testing techniques could be easily inserted at several points. No calculus is required, although differential equations could be inserted in the consumers' surplus calculations if desired.

A strong effort has been made to use variable notation which enables time and regional aggregation and disaggregation if needed (acres treated by pesticides are available at the county level from the Census of Agriculture), and these same variables are suitable for the development of simple programs to use, for example, in programmable calculators.

The approach of each submodel is to describe the general types of data needed and the probable alternative sources for these data rather than the present the user with a highly specified set of precisely defined variables. This approach is intended to provide the user with good flexibility in structuring his own benefit-cost accounts, within the basic system structure provided. Such an approach, however, does not simplify the use of the system to the cookbook level. Any user will find it extremely useful to have a working familiarity with the agricultural experiment literature, the experimental animal toxicity literature, and the monitoring studies of environmental residues.

Thus, any user who enters the system with a given pesticide will be forced to imagine a scenario of use in terms of types of crops and pests. He may well need to refer to some published sources on application rates and toxicity (e.g., the EPA compendium) such as those referenced in the sections for each submodel.

After developing a few of the specifically formatted tables, the user may then choose to devise his own summary formats for a given geographic level. In any case, working through the system for a given pesticide, which is expected to require two to four work-weeks, will lead the user to a complete use of the best available data, by means of a series of logically sound data reduction algorithms.

APPENDIX A

TAXONOMIES FOR ALTERNATIVE PEST CONTROL METHODS

Definition of Pests. Public Law 92-516, October 21, 1972

The term pest means (1) any insect, rodent, nematode, fungus, weed, or (2) any other form of terrestrial or aquatic plant or animal life or virus, bacteria, or other micro-organism (except viruses, bacteria, or other micro-organisms on or in living man or other living animals) which the Administrator declares to be a pest.

I. Taxonomy of Commonly Recognized Pests
  A. Plant pathogens -- plant disease
    1. Viruses
    2. Mycoplasma
    3. Bacteria
      a. Actinomycetes
    4. Fungi
    5. Parasitic vascular plants
    6. Nematodes
  B. Weeds
    Any and all kinds of chlorophyll-bearing vascular plants may be considered weeds at one time or another. A weed is a plant out of place, an unwanted plant.
  C. Insects and Other Arthropods
    1. Insects
    2. Arachnids
      a. Mites
      b. Spiders
      c. Ticks
  D. Vertebrates
    1. Fish
    2. Reptiles
    3. Birds
    4. Mammals
      a. Chiroptera -- bats
      b. Lagomorpha -- rabbits
      c. Rodentia -- rodents
      d. Carnivora -- coyote, etc.

II. Taxonomy of Alternatives for Control of Plant Pathogens Including Nematodes and Parasitic Vascular Plants

- A. Genetic resistance, tolerance, or immunity on the part of the host plant, crop, or commodity
  - 1. Resistance
    - a. Vertical
    - b. Horizontal
  - 2. Tolerance
  - 3. True immunity
- B. Biological Control
  - 1. Parasites
  - 2. Predators
  - 3. Competitive displacement of organismal populations
    - a. Antagonism
      - i. Antibiosis
    - b. Food substrate competition
- C. Cultural Control
  - 1. Geographic avoidance and planting site selection
  - 2. Tillage
  - 3. Rotation
  - 4. Planting date
  - 5. Harvesting and storage
  - 6. Thinning
  - 7. Pruning
  - 8. Water management
  - 9. Plant nutrition
  - 10. Vegetation barriers
  - 11. Elimination of diseased plants
  - 12. Elimination of alternate hosts
- D. Physical and Mechanical Control
  - 1. Environmental modification
    - a. Heat
    - b. Cold
    - c. Humidity
    - d. Air composition
    - e. Water
  - 2. Barriers
    - a. Terrain and governmental quarantine
  - 3. Radiation
- E. Chemical Control
  - 1. Protectants and surface eradicants
    - a. Foliage, fruit
    - b. Seed and other propagules

2. Systemic protectants -- eradicants
   a. Local
   b. Xylem translocated
   c. Phloem translocated
3. Theraputants
4. Growth regulants
   a. Chemical resistance and immunity
5. Soil sterilants and eradicants

III. Taxonomy of Alternatives for Control of Weed Plants
   A. Genetic tolerance to competition from weeds
      1. Growth habit
      2. Root structure
      3. Nutrient or moisture utilization
   B. Biological Control
      1. Parasites
      2. Predators
      3. Pathogens, i.e., infectious diseases
   C. Cultural Control
      1. Tillage
      2. Rotation
      3. Crop refuse removal
      4. Land utilization
      5. Plant nutrition
      6. Harvesting methods
      7. Thinning
      8. Water management
      9. Geographic avoidance
   D. Physical and Mechanical Control
      1. Pulling, chopping, or cutting removal
      2. Cultivation by hoe or mechanical equipment
      3. Heat
      4. Barriers
         a. Materials
            i. to keep out light
            ii. to prevent top or root penetration
         b. Terrain
         c. Electricity
   E. Chemical Control
      1. Growth regulation
         a. Inhibition or stimulation
         b. Sterilization
         c. Malformation
      2. Intoxication

IV. Taxonomy of Alternatives for Control of Insects and Other Arthropods

Definition:

Control is defined as the regulation, guiding, or management of a process or system; in this case, the system is the ecosystem within which the insect lives and reproduces.

A. Genetic resistance or tolerance on the part of the host plant, animal, or commodity
   1. Repellency
   2. Intoxication
   3. Indirect effects on arthropod population

B. Biological Control
   1. Parasites
   2. Predators
   3. Pathogens, i.e., infectious diseases
   4. Genetic manipulation of insect populations
   5. Competitive displacement of insect populations by other insects

C. Cultural Control
   1. Sanitation
   2. Tillage
   3. Rotation
   4. Crop refuse destruction
   5. Land utilization
   6. Plant nutrition
   7. Harvesting and storage
   8. Thinning
   9. Pruning
   10. Water management
   11. Geographic avoidance and planting site selection

D. Physical and Mechanical Control
   1. Heat
   2. Cold
   3. Humidity
   4. Radiant energy
      a. Light traps
      b. Light regulation
   5. Sound

        6. Barriers
            a. Terrain and governmental quarantine
            b. Adhesives
            c. Material
            d. Air
            e. Water
            f. Electric
        7. Traps
        8. Radiation
            a. Sterilization
            b. Intoxication
    E. Chemical Control
        1. Attractants (combined with other methods)
        2. Repellents
        3. Sterilization
        4. Growth regulation (juvenile hormones, etc.)
        5. Intoxication (insecticide)

V. Taxonomy of Alternatives for Control of Vertebrates
    A. Genetic resistance or tolerance on the part of the host plant, animal, or commodity
        1. Repellency
        2. Intoxication
    B. Biological Control
        1. Predators
        2. Pathogens, i.e., infectious diseases
        3. Competitive displacement of pest vertebrate through ecological manipulation with other organisms
    C. Physical and Mechanical Control
        1. Traps
        2. Sound
        3. Light
        4. Heat
        5. Cold
        6. Barriers
        7. Sanitation
        8. Den, burrow or nest removal
    D. Cultural Control
        1. Tillage
        2. Biological barrier
        3. Crop rotation
        4. Sanitation, i.e., crop or animal refuse or waste removal

    5. Land or water utilization
    6. Harvesting techniques
    7. Manipulation of plant or animal cultural practices
        a. Pruning
        b. Housing
        c. Planting or stocking procedures

E. Chemical Control
    1. Attractants
    2. Repellants
    3. Sterilization or reproductive impairment
    4. Growth regulation
    5. Intoxication

APPENDIX B

BENEFITS AND COSTS FROM PEST CONTROL

I. Pesticide Benefits-Costs: Food, Feed, and Fiber Production and Utilization

- A. Entities Receiving Benefits or Incurring Costs
  - 1. Private institutions, agency or individual
    - a. Manufacturer of pesticide
    - b. Formulator
    - c. Distributor
    - d. Wholesaler-retailer
    - e. Applicator
    - f. Agricultural producer
    - g. Field worker
    - h. Commodity-crop processor
    - i. Distributor-wholesaler
    - j. Retailer
    - k. Consumer
  - 2. Public agencies
    - a. Federal government
    - b. State government
    - c. Local government
  - 3. Society as a whole
  - 4. Non-human environmental components
    - a. Marine aquatic
      - i. Phytological
      - ii. Zoological
    - b. Fresh-water aquatic
      - i. Phytological
      - ii. Zoological
    - c. Terrestrial
      - i. Phytological
      - ii. Zoological
- B. Pesticide Benefits Taxonomy
  - 1. Invention, production, and distribution system of pesticide
    - a. Increased production of goods by manufacturer
    - b. Increased sales
    - c. Conversion of natural resource to marketable goods
    - d. Gainful employment of people
    - e. Monetary profit
  - 2. Use in food, feed or fiber production system
    - a. Increased yield
    - b. Improved quality or reduced pest losses as assessed in market place
      - i. Larger size

ii. Better taste
iii. More usable qualities
iv. Free from defect, worms, rots, molds
v. Better storage or shelf life
vi. More suitable for intended purpose
c. Increased monetary profit
3. Food, feed, and fiber processing, utilization, and distribution
  a. Freedom from defects or more suitable for intended use
  b. Better storage and shelf life
  c. Prevention of molds, rots, toxins
  d. Reduced loss from spoilage
  e. Increased monetary profit
4. Consumer
  a. Improved quality
    i. Taste, shelf life, appearance
    ii. Free from defects
    iii. Free from spoilage or toxins
    iv. Better storage
    v. More suitable for intended purpose
    vi. More healthful
  b. Lower purchase price
  c. Non-hazardous pesticide residue
5. Public agencies
  a. Less toxic or hazardous, less need for public agency regulation
  b. Lower regulatory or administrative costs
6. Non-human environmental components
  a. Less toxic to various components in all phases of the environment
  b. Non-hazardous pesticide residue
    i. Does not accumulate in food chain
    ii. Is not persistent in environment

C. Pesticide Costs Taxonomy
1. Invention, production, and distribution systems of pesticides
  a. Utilization of scientific resources in discovery and development
  b. Utilization of natural resources in manufacture
  c. Utilization of human labor and technical skills in manufacture

d. Utilization of manufacturing facilities
e. Exposure of humans to pesticide during development, manufacture and distribution
    i. Human physiologic effects
        - Acute injury
        - Chronic injury
            . Mutagenicity
            . Teratogenicity
            . Oncogenicity
            . Reproductive impairment
            . Chronic physiologic malfunction
f. Spillage and accidental release of pesticides to environment
g. Human resources and physical facilities in distribution and marketing
h. Monetary resources in development, manufacture, and distribution

2. Use in food, feed or fiber production systems
    a. Monetary cost to agricultural producer for pesticide
    b. Resources used in application
        i. Monetary cost of applicator services
        ii. Utilization of human resources by applicator and employees
    c. Storage and disposal of pesticides and containers
    d. Spillage and breakage loss and cleanup costs
    e. Health effects to applicator and agricultural producer employees working treated area
        i. Acute
            - Normal use*
            - Accidental exposure and spills

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*In this instance and throughout the entire taxonomy, acute injury from normal use is included to reflect the real world situation. Ideally, there should be no such term as "acute injury from 'normal' exposure." Yet, many would argue, e.g., those in industry, that any acute injury that is caused from direct exposure to a pesticide is not all a result of accidental release. Therefore, until this issue is resolved, one can argue that some acute injury is caused by what many refer to as "normal" exposure.

ii. Chronic effects
  - Mutagenicity
  - Teratogenicity
  - Oncogenicity
  - Reproductive impairment
  - Chronic physiologic malfunction

f. Production system constraints induced by pesticide use
  i. Spray intervals -- harvest dates
  ii. Re-entry intervals
  iii. Cultural practices

g. Treadmill effect, i.e., additional pest control costs
  i. Induced pest resistance
  ii. Destruction of predators

3. Food, feed, and fiber processing, utilization, and distribution
  a. Residue removal
  b. Constraints on byproduct utilization or treatment of processing wastes due to pesticide residues
  c. Exposure of employees to pesticide residues
    i. Acute
      - Normal use
      - Accidental exposure and spills
    ii. Chronic
      - Mutagenicity
      - Teratogenicity
      - Oncogenicity
      - Reproductive impairment
      - Chronic physiologic malfunction

4. Consumer
  a. Higher purchase price
  b. Use constraints
    i. Washing, peeling to remove residue
  c. Exposure to residue and human health effects
    i. Acute injury
    ii. Chronic effects
      - Mutagenicity
      - Teratogenicity
      - Oncogenicity
      - Reproductive impairment
      - Chronic physiologic malfunction

5. Public agencies
    a. Pesticide research and development; human and monetary resources
        i. Federal government
        ii. State government
        iii. Land grant experiment stations
    b. Human and environmental health effects research; human and monetary resources
        i. Federal government
        ii. State government
        iii. Medical research institutes
    c. Regulation of pesticides; human and monetary resources

6. Non-human environmental components
    a. Acute toxicity
    b. Chronic toxicity
        - Mutagenicity
        - Teratogenicity
        - Oncogenicity
        - Reproductive impairment
        - Chronic physiologic malfunction

II. Pesticide Benefit-Cost: Health/Disease Vector Nuisance Pests
  A. Entities receiving benefits or incurring costs
    1. Private institutions, agency or individual
        a. Manufacturer of pesticide
        b. Formulator
        c. Distributor
        d. Wholesaler-retailer
        e. Applicator
        f. Private individual
        g. People-oriented business, i.e., recreation-vacation enterprise
    2. Public agency
        a. Federal government
        b. State government
        c. Local government
    3. Society as a whole
    4. Non-human environmental components
        a. Marine aquatic
            i. Phytological
            ii. Zoological

- b. Freshwater aquatic
  - i. Phytological
  - ii. Zoological
- c. Terrestrial
  - i. Phytological
  - ii. Zoological

B. Pesticide Benefits Taxonomy

- 1. Invention, production, and distribution system of pesticide
  - a. Increased production of goods by manufacturer
  - b. Increased sales
  - c. Conversion of natural resource to marketable goods
  - d. Gainful employment of people
  - e. Monetary profit

- 2. Use in human disease vector and nuisance pest suppression
  - a. Gainful employment of pesticide applicator
    - i. Monetary profit to business
    - ii. Employment and wages to employees
  - b. Suppression or elimination of disease or nuisance pests
    - i. Better level of health of people in treated areas
      - More productivity
      - Better outlook on life
      - Lower expenses for medical care
      - More satisfying life; fewer frustrations
      - Less wastage of food, clothing, other resources
      - Freedom to move around outside without fear of disease
  - c. Enhancement of life or business enterprises in treated areas
    - i. Homes or residences where previously unsuitable
    - ii. Business such as resorts where previously not successful
- 3. Public agencies
  - a. Less need for governmental inputs
    - i. Fewer health surveys
    - ii. Fewer public health programs
    - iii. Less hospital care of indigent
    - iv. Fewer educational programs

4. Society as a whole
    a. Less disease
    b. Happier, more content populace
    c. Better population distribution
    d. More productive populace
    e. Greater carrying capacity of the land or national land area
5. Non-human environmental components
    a. Enhanced survival of certain wildlife components

C. Pesticide Costs Taxonomy
1. Invention, production, and distribution systems of pesticides
    a. Utilization of scientific resources in discovery and development
    b. Utilization of natural resources in manufacture
    c. Utilization of human labor and technical skills in manufacture
    d. Utilization of manufacturing facilities
    e. Exposure of humans to pesticide during development, manufacture, and distribution
        i. Human physiologic effects
            - Acute injury
            - Chronic
                . Mutagenicity
                . Teratogenicity
                . Oncogenicity
                . Reproductive impairment
                . Chronic physiologic malfunction
    f. Spillage and accidental release of pesticides to environment
    g. Human resources and physical facilities in distribution and marketing
    h. Monetary resources in development, manufacture, and distribution
2. Use in human disease vector and nuisance pest suppression
    a. Monetary cost for pesticide
    b. Resources used in application
        i. Monetary cost of applicator services
        ii. Utilization of human resources by applicator and employees
    c. Storage and disposal of pesticides and containers
    d. Spillage and breakage loss and cleanup costs

e. Health effects to applicators and employees or householders or other pesticide users
    i. Acute effects
        - Normal use
        - Accidental exposure and spills
    ii. Chronic effects
        - Mutagenicity
        - Teratogenicity
        - Oncogenicity
        - Reproductive impairment
        - Chronic physiologic malfunction
f. Treadmill effect, i.e., additional pest control costs
    i. Induced pest resistance
    ii. Destruction of predators

3. People, lands, plants, facilities or structures receiving treatment
    a. Damage to facilities or structures
        i. Discoloration, residues, etc.
    b. Health effects to people living or working in/on treated lands or structures
        i. Acute
            - Normal use
            - Accidental exposure and spills
        ii. Chronic effects
            - Mutagenicity
            - Teratogenicity
            - Oncogenicity
            - Reproductive impairment
            - Chronic physiologic malfunction
4. Public agencies
    a. Pesticide research and development; human and monetary resources
        i. Federal government
        ii. State government
        iii. Land grant experiment stations
    b. Human and environmental health effects research; human and monetary resources
        i. Federal government
        ii. State government
        iii. Medical research institutes
    c. Regulation of pesticides; human and monetary resources

- 5. Non-human environmental components
    - a. Acute toxicity
    - b. Chronic toxicity
        - i. Mutagenicity
        - ii. Teratogenicity
        - iii. Oncogenicity
        - iv. Reproductive impairment
        - v. Chronic physiologic malfunction

- III. Pesticide Benefit-Cost: Commercial-Industrial Use
    - A. Entities receiving benefits or incurring costs
        - 1. Private institutions, agency or individual
            - a. Manufacturer of pesticide
            - b. Formulator
            - c. Distributor
            - d. Wholesaler
            - e. Applicator
            - f. Commercial or industrial user (purchase of product or service from industry or business)
            - g. Distributor
            - h. Retailer
            - i. Consumer
        - 2. Public agencies
            - a. Federal government
            - b. State government
            - c. Local government
        - 3. Society as a whole
        - 4. Non-human environmental components
            - a. Marine aquatic
                - i. Phytological
                - ii. Zoological
            - b. Freshwater aquatic
                - i. Phytological
                - ii. Zoological
            - c. Terrestrial
                - i. Phytological
                - ii. Zoological
    - B. Pesticide Benefits Taxonomy
        - 1. Invention, production, and distribution system of pesticide
            - a. Increased production of goods by manufacturer
            - b. Increased sales
            - c. Conversion of natural resource of marketable goods

- d. Gainful employment of people
- e. Monetary profit

2. Use in pest suppression
    - a. Gainful employment of pesticide applicator
        - i. Monetary profit to business
        - ii. Employment and wages to employees
    - b. Suppression of problem pest
        - i. Hazardous vegetation eliminated
            - Fewer damages to utility wires from trees
                - . Lower right-of-way maintenance costs
            - Better visibility along roads
                - . Fewer accidents to motorists
                    - .. Fewer injuries and loss of life
                    - .. Less waste of materials, i.e., vehicles
            - Fewer fires along railroads and industrial sites
                - . Less property damage
                - . Fewer injuries and loss of life
        - ii. Reduction in materials and property loss
            - Less wood decay and insect damage
                - . Less waste of materials and resources
3. Public agencies
    - a. Lower maintenance costs for roads
    - b. Lower police and traffic safety costs associated with accident investigation
4. Society as a whole
    - a. Reduction or elimination of hazardous vegetation
        - i. Reduction in loss of human resources
        - ii. Reduction in loss of material resources

C. Pesticide costs taxonomy

1. Invention, production, and distribution systems of pesticides
    - a. Utilization of scientific resources in discovery and development
    - b. Utilization of natural resources in manufacture
    - c. Utilization of human labor and technical skills in manufacture
    - d. Utilization of manufacturing facilities
    - e. Exposure of humans to pesticide during development, manufacture, and distribution

        i. Human physiologic effects
            - Acute injury
            - Chronic
                . Mutagenicity
                . Teratogenicity
                . Oncogenicity
                . Reproductive impairment
                . Chronic physiologic malfunction
    f. Spillage and accidental release of pesticides to environment
    g. Human resources and physical facilities in distribution and marketing
    h. Monetary resources in development, manufacture, and distribution
2. Use in commercial industrial situations
    a. Monetary cost for pesticide
    b. Resources used in application
        i. Monetary cost of applicator services
        ii. Utilization of human resources by applicator and employees
    c. Storage and disposal of pesticides and containers
    d. Spillage and breakage loss and cleanup costs
    e. Health effects to applicators and employees or other pesticide users
        i. Acute effects
            - Normal use
            - Accidental exposure and spills
        ii. Chronic effects
            - Mutagenicity
            - Teratogenicity
            - Oncogenicity
            - Reproductive impairment
            - Chronic physiologic malfunction
    f. Treadmill effect, i.e., additional pest control costs
        i. Induced pest resistance
        ii. Destruction of predators
3. People, lands, plants, facilities or structures receiving treatment
    a. Damage to facilities or structures
        i. Discoloration, residues, etc.

b. Health effects to people living or working in/on treated lands or structures
i. Acute
- Normal use
- Accidental exposure and spills

ii. Chronic effects
- Mutagenicity
- Teratogenicity
- Oncogenicity
- Reproductive impairment
- Chronic physiologic malfunction

4. Public agencies
a. Pesticide research and development; human and monetary resources
i. Federal government
ii. State government
iii. Land grant experiment stations
b. Human and environmental health effects research; human and monetary resources
i. Federal government
ii. State government
iii. Medical research institutes
c. Regulation of pesticides; human and monetary resources
5. Non-human environmental components
a. Acute toxicity
b. Chronic toxicity
i. Mutagenicity
ii. Teratogenicity
iii. Oncogenicity
iv. Reproductive impairment
v. Chronic physiologic malfunction

IV. Pesticide Benefit-Cost: Aesthetic Improvement
A. Entities receiving benefits or incurring costs
1. Private institutions, agency, or individual
a. Manufacturer of pesticide
b. Formulator
c. Distributor
d. Wholesaler-retailer
e. Applicator
f. Private individual
g. People-oriented business, i.e., resort, campground, golf course

2. Public agency
    a. Federal government
    b. State government
    c. Local government
3. Society as a whole
4. Non-human environmental components
    a. Marine aquatic
        i. Phytological
        ii. Zoological
    b. Freshwater aquatic
        i. Phytological
        ii. Zoological
    c. Terrestrial
        i. Phytological
        ii. Zoological

B. Pesticide Benefits Taxonomy
1. Invention, production, and distribution system of pesticides
    a. Increased production of goods by manufacturer
    b. Increased sales
    c. Conversion of natural resource to marketable goods
    d. Gainful employment of people
    e. Monetary profit
2. Use in pest suppression and aesthetic improvement
    a. Gainful employment of pesticide applicator
        i. Monetary profit to business
        ii. Employment and wages to employees
    b. Suppression or elimination of pest
        i. More pleasing appearance to treated plants, animals, or landscape area
            - Higher value of homes, neighborhood, community
            - More happy or content people
            - Greater attractiveness of recreation or resort area (monetary profit to owners, employment and wages to employees)
            - Better distribution of residences and business in geographic sense
3. Public agencies
    a. Less need for governmental inputs
        i. Chemical weeding -- reduced costs
    b. High value real estate -- bigger tax base
        i. Homes
        ii. Businesses -- resorts, etc.

4. Society as a whole
    a. More pleasant surroundings for life
    b. More content people

C. Pesticide Costs Taxonomy
    1. Invention, production, and distribution system of pesticides
        a. Utilization of scientific resources in discovery and development
        b. Utilization of natural resources in manufacture
        c. Utilization of human labor and technical skills in manufacture
        d. Utilization of manufacturing facilities
        e. Exposure of humans to pesticide during development, manufacture, and distribution
            i. Human physiologic effects
                - Acute injury
                - Chronic
                    . Mutagenicity
                    . Teratogenicity
                    . Oncogenicity
                    . Reproductive impairment
                    . Chronic physiologic malfunction
        f. Spillage and accidental release of pesticides to environment
        g. Human resources and physical facilities in distribution and marketing
        h. Monetary resources in development, manufacture, and distribution
    2. Use in human aesthetic improvement
        a. Monetary cost for pesticide
        b. Resources used in application
            i. Monetary cost of applicator services
            ii. Utilization of human resources by applicator and employees
        c. Storage and disposal of pesticides and containers
        d. Spillage and breakage loss and cleanup costs
        e. Health effects to applicators and employees or householders or other pesticide users
            i. Acute effects
                - Normal use
                - Accidental exposure and spills

- ii. Chronic effects
  - Mutagenicity
  - Teratogenicity
  - Oncogenicity
  - Reproductive impairment
  - Chronic physiologic malfunction
- f. Treadmill effect, i.e., additional pest control costs
  - i. Induced pest resistance
  - ii. Destruction of predators

3. People, lands, plants, facilities or structures receiving treatment
   - a. Damage to facilities or structures
     - i. Discoloration, residues, etc.
   - b. Health effects to people living or working in/on treated lands or structures
     - i. Acute
       - Normal use
       - Accidental exposure and spills
     - ii. Chronic effects
       - Mutagenicity
       - Teratogenicity
       - Oncogenicity
       - Reproductive impairment
       - Chronic physiologic malfunction
4. Public agencies
   - a. Pesticide research and development; human and monetary resources
     - i. Federal government
     - ii. State government
     - iii. Land grant experiment stations
   - b. Human and environmental health effects research; human and monetary resources
     - i. Federal government
     - ii. State government
     - iii. Medical research institutes
   - c. Regulation of pesticides; human and monetary resources
5. Non-human environmental components
   - a. Acute toxicity

        b. Chronic toxicity
            i. Mutagenicity
            ii. Teratogenicity
            iii. Oncogenicity
            iv. Reproductive impairment
            v. Chronic physiologic malfunction

V. Pesticide Benefit-Cost: Environmental Management
  A. Entities receiving benefits or incurring costs
    1. Private institutions, agency or individual
        a. Manufacturer of pesticide
        b. Formulator
        c. Distributor
        d. Wholesaler
        e. Applicator
        f. Private individual
        g. People-oriented business, i.e., resorts, etc.
    2. Public agencies
        a. Federal government
        b. State government
        c. Local government
    3. Society as a whole
    4. Non-human environmental components
        a. Marine aquatic
            i. Phytological
            ii. Zoological
        b. Freshwater aquatic
            i. Phytological
            ii. Zoological
        c. Terrestrial
            i. Phytological
            ii. Zoological
  B. Pesticide Benefits Taxonomy
    1. Invention, production, and distribution system of pesticide
        a. Increased production of goods by manufacturer
        b. Increased sales
        c. Conversion of natural resource to marketable goods
        d. Gainful employment of people
        e. Monetary profit

2. Use in pest suppression and environmental management
    a. Gainful employment of pesticide applicator
        i. Monetary profit to business
        ii. Employment and wages to employees
    b. Suppression or elimination of pest
        i. Enhanced quality of environment
            - More pleasing appearance of ecosystem
            - Higher property values (greater attractiveness of recreation areas and resorts in improved area)
            - Better distribution of residences and businesses in geographic sense
3. Public agencies
    a. Lower dollar inputs in environmental maintenance programs
        i. Game and fish agencies
        ii. Forestry and environmental agencies
4. Society as a whole
    a. Enhancement or preservation of environmental components given value by man
5. Non-human environmental components
    a. Maintenance of balanced ecosystems

C. Pesticide Costs Taxonomy
1. Invention, production, and distribution systems of pesticides
    a. Utilization of scientific resources in discovery and development
    b. Utilization of natural resources in manufacture
    c. Utilization of human labor and technical skills in manufacture
    d. Utilization of manufacturing facilities
    e. Exposure of humans to pesticide during development, manufacture, and distribution
        i. Human physiologic effects
            - Acute injury
            - Chronic
                . Mutagenicity
                . Teratogenity
                . Oncogenicity
                . Reproductive impairment
                . Chronic physiologic malfunction
    f. Spillage and accidental release of pesticides to environment

- g. Human resources and physical facilities in distribution and marketing
- h. Monetary resources in development, manufacture, and distribution

2. Use in environmental management
    - a. Monetary cost for pesticide
    - b. Resources used in application
        - i. Monetary cost of applicator services
        - ii. Utilization of human resources by applicator and employees
    - c. Storage and disposal of pesticides and containers
    - d. Spillage and breakage loss and cleanup costs
    - e. Health effects to applicators and employees or other pesticide users
        - i. Acute effects
            - Normal use
            - Accidental exposure and spills
        - ii. Chronic effects
            - Mutagenicity
            - Teratogenicity
            - Oncogenicity
            - Reproductive impairment
            - Chronic physiologic malfunction
    - f. Treadmill effect, i.e., additional pest control costs
        - i. Induced pest resistance
        - ii. Destruction of predators
3. People, lands, plants, facilities or structures receiving treatment
    - a. Damage to facilities or structures
        - i. Discoloration, residues, etc.
    - b. Health effects to people living or working in/on treated lands or structures
        - i. Acute
            - Normal use
            - Accidental exposure and spills
        - ii. Chronic effects
            - Mutagenicity
            - Teratogenicity
            - Oncogenicity
            - Reproductive impairment
            - Chronic physiologic malfunction

4. Public agencies
    a. Pesticide research and development; human and monetary resources
        i. Federal government
        ii. State government
        iii. Land grant experiment stations
    b. Human and environmental health effects research; human and monetary resources
        i. Federal government
        ii. State government
        iii. Medical research institutes
    c. Regulation of pesticides; human and monetary resources
5. Non-human environmental components
    a. Acute toxicity
    b. Chronic toxicity
        i. Mutagenicity
        ii. Teratogenicity
        iii. Oncogenicity
        iv. Reproductive impairment
        v. Chronic physiologic malfunction

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1.1

2.0 SUMMARY OF RESULTS 2.1

- 2.1 General Information Concerning the Structure of the Case Study 2.1
- 2.2 Agricultural Impacts 2.2
- 2.3 Health Effects 2.4
- 2.4 Environmental Impacts 2.6
- 2.5 Net Benefits from Use of Fenox When Substituted for Delta 2.8
- 2.6 Critique and Feasibility of the Benefit-Cost System 2.9
  - 2.6.1 Difficulties in the Submodel Approach 2.9
  - 2.6.2 Difficulties in Formatting Results 2.11
  - 2.6.3 Difficulties in Obtaining Input Data 2.13
  - 2.6.4 Difficulties in the Conceptual Design of the Benefit-Cost System 2.15

3.0 AGRICULTURAL IMPACTS 3.1

- 3.1 Net Internal Benefits to Society 3.1
  - 3.1.1 Acres of Crops Treated with Fenox 3.2
  - 3.1.2 Net Changes in Crop Yield 3.6
  - 3.1.3 Net Changes in Crop Prices 3.13
  - 3.1.4 Change in Consumers' Surplus 3.20
- 3.2 Net Costs of Pesticide Application 3.20

4.0 HEALTH EFFECTS 4.1

- 4.1 Description of Study Pesticide and Its Next Best Alternative 4.1

TABLE OF CONTENTS (continued)

Page

4.2 Subpopulation at Risk 4.1
  4.2.1 Pesticide R and D, Manufacturing and Formulation Workers 4.2
  4.2.2 Field Workers and Other Farm Personnel 4.2
  4.2.3 Commercial Farm Applicators 4.4
  4.2.4 Society As A Whole 4.7
4.3 Net Health Damages 4.10
  4.3.1 Determination of Net Health Damages Using Animal Toxicology Data 4.10
    4.3.1.1 Acute Injury Assessment 4.10
      4.3.1.1.1 Ocular Exposure Hazard 4.13
      4.3.1.1.2 Dermal Exposure Hazard 4.15
      4.3.1.1.3 Oral Exposure Hazard 4.18
      4.3.1.1.4 Inhalation Exposure Hazard 4.18
      4.3.1.1.5 Percutaneous Exposure Hazard 4.19
      4.3.1.1.6 Systemic Poisoning Hazard 4.19
      4.3.1.1.7 Death Hazard 4.20
    4.3.1.2 Chronic Injury Assessment 4.20
      4.3.1.2.1 Metabolism and Elimination 4.21
      4.3.1.2.2 Mutagenic Hazard 4.22
      4.3.1.2.3 Teratogenic Hazard 4.23
      4.3.1.2.4 Oncogenic Hazard, Reproductive Impairment, and Physiological Malfunction Hazard 4.24

TABLE OF CONTENTS (continued)

Page

4.3.2 Determination of Net Health Damages Using Human Experience Data 4.26
4.3.2.1 Acute and Chronic Injury to R and D, Manufacturing and Formulation Workers 4.26
4.3.2.2 Acute and Chronic Injury to Field Workers and Other Farm Personnel 4.29
4.3.2.3 Acute and Chronic Injury to Commercial Farm Applicators 4.32
4.3.2.4 Acute and Chronic Injury to Society 4.34
4.3.3 Summary of Net Health Damages 4.36
4.4 Net Health Benefits 4.40

5.0 ENVIRONMENTAL IMPACTS 5.1

5.1 Introduction 5.1
5.2 Transport and Accumulation 5.2
5.3 Impacts on Biological Systems 5.10
5.4 Values of Ecologic Damages 5.14
Attachment 5.1: Alternative Method to Calculate Environmental Hazard from Surface Runoff of Fenox or Delta 5.23
Attachment 5.2: A Method of Calculating the Quantity of Fish in Inland Waters by Region 5.30

APPENDIX A: Agricultural Analysis of the Use of Pesticide Alternatives to DDT on Sweet Potatoes, Sweet Corn and Peanuts in 1973 and 1974 A.1

1.0 INTRODUCTION

In this volume of the report, the benefit-cost system for analyzing the use of chemical pesticides is described in the form of a case study. The benefit-cost system described is constructed as a set of submodels connected by data transfers, and it is divided into separate submodels for convenience of application.

The case study application is intended solely to illustrate the use of the system, while simultaneously providing a descriptive presentation of its procedures, formulations, underlying assumptions, and data requirements. Since the case study is only illustrative, it is applied to an hypothetical pesticide which has chemical features borrowed from a class of presently registered, well-known pesticides: the phenoxy herbicide group, including 2,4-D; 2,4,5-T; MCPA; and Silvex.* Other members of the phenoxy group were reviewed, but data were most readily available on the four named.

The hypothetical herbicide fabricated from these data is called "Fenox." Fenox is defined as a pre- and post-emergence herbicide suitable for multiple treatments of wheat, oats, and barley. Thus, the herbicide has broad applicability and its use might be expected to be geographically widespread. The study assumes that Fenox has not yet been registered, but that it has been tested extensively on the three crops mentioned, and that some basic test data are available on its health effects and environmental activity. In some calculations, averages of parameters from the phenoxy herbicide group were used. For example, an estimate of the number of acres to which Fenox would be applied was made, based on the number of acres to which phenoxy herbicides had been applied in the past. In other cases, the parameters (degradation rates, toxicity, water solubility, and other features) were selected from one or another of the group. The particular herbicide reflected in many calculations is not identified, in order to preserve the hypothetical and illustrative nature of the analysis.

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*These pesticides are defined as follows: 2,4-D - 2,4-Dichlorophenoxyacetic acid; 2,4,5-T - 2,4,5-Trichlorophenoxyacetic acid; MCPA - 2-methyl-4-chlorophenoxyacetic acid; and Silvex - 2-(2,4,5-trichlorophenoxy) propionic acid.

Given the above two assumptions about Fenox (i.e., that Fenox is proposed for registration but not yet registered, and that extensive testing has been performed), it is important to understand the alternatives available to EPA decision-makers, and thus to society as a whole, when assessing the request to register Fenox.

First, the decision-makers could choose not to register Fenox. This alternative implies that they have decided it presents an unreasonable hazard to man and his environment. In order to assess the effects of non-registration, some broad assumptions must be made about what practices farmers are now using and what they are likely to be doing during the five-year registration period. One simple assumption is that farmers will continue to engage in their present practices, whether these are mechanical cultivation, flame suppression of weeds or some alternative chemical herbicide. This state of affairs could be analyzed in detail if comprehensive data were available on farming practices in areas where the three crops are grown. But such data probably would be attained only by a direct, costly survey. In addition, how can the farmer's reaction to a newly registered pesticide be predicted? Each individual farmer will compare the potential of the new product to the features of his present weed control program and react according to the outcome of his own benefit-cost analysis. The reaction could result in a greater input of chemicals into the environment -- no matter what the EPA does.

This same statement is true if the EPA does, in fact, register the new pesticide Fenox. The reaction could involve a greater or less insult to the environment, depending on the cost of alternatives to the farmer, the size of his farm, his mix of crops, and his expected crop value. In other words, the farmer begins each season with an almost clean slate. He knows that some level of infestation will occur, that some pesticide residual probably remains in the ground, and that some increase in immunity has occurred since the previous season. For the coming season he has an array of alternatives which will include not only choices of single pest control measures but also combinations of mechanical, chemical, biological, and other strategies. One of his choices could be a pesticide newly registered by EPA, but sophisticated models for analyzing the numerous pest control strategies and predicting what most farmers will do are not readily available.

The above discussion implies that in order for the EPA to properly consider its own alternatives, the EPA must have available a highly sophisticated model of the farmer's consideration of his alternatives.

The benefit-cost analysis presented in this report can avoid the farmer decision problem by two tactics:

- It can assume that the farmer faces the possibility of using either Fenox or weed control measures which are non-chemical and thus that have almost no health or environmental impact, or

- It can assume that some proportion of present crop acreage will be treated with the new herbicide if it is registered.

The first assumption lacks realism in the sense that the farmer who has been using a chemical herbicide will probably continue to do so on those acres where weeds are a severe problem. It is arguable, however, that a sufficient increase in herbicide prices would force him either to change his acreage or to revert to mechanical methods. If he decides to change his acreage, he may increase acreage and reduce his weed control costs, or he may reduce acreage and adopt more expensive (mechanical or higher-priced chemical) methods in order to maintain constant yield per dollar of investment. Thus, he may change acreage and/or shift to mechanical weed control methods. The alternatives which are hypothetically open to each farmer are numerous, although, in fact, any on an individual farmer may be severely restricted.

The second assumption is more realistic than the first. A new herbicide entering the market is likely to have at least one major advantage: there is no widespread immunity to it. Thus, Fenox, if registered, would prove attractive to many farmers if its price were reasonably competitive.

The two assumptions lead to the development of one possible scenario which provides a basis for the benefit-cost analysis presented in this volume of the report. In this scenario, the farmers who raise wheat, oats, and barley are faced with probable obsolescence* of several herbicides sometime in the future and have a choice of continuing

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*For a discussion of obsolescence, see G. K. Kohn, "The Pesticide Industry," in James A. Kent (ed.), Riegel's Handbook of Industrial Chemistry, 7th Edition, New York, Van Nostrand Reinhold, Chapter 1, 1974, p. 624.

with the herbicide presently used, and/or replanning their acreage utilization, and/or adopting different (and perhaps more costly) weed control measures, including new pesticides, and/or rejecting all pest control measures. Of these four major strategies, the farmer can hold his costs constant with respect to previous years by continuing with the herbicide presently used or by expanding acreage and reducing weed control measures. In the latter case, his savings on weed control will be applied to increased costs of cultivation.

The above discussion has described how the EPA decision-maker's alternatives and the farmer's alternatives are closely interconnected. CONSAD Research Corporation recommends that the OPP acquire and use a set of simple, concise, flexible farm budget models for use in estimating probable farmer reactions to a regulatory decision. The important point in the preceding discussion is that alternative farmer reactions must be clearly structured before the EPA alternatives -- which are limited to register, deny registration, or cancellation -- can become meaningful.

The EPA, in spite of certain powers derived from its authority to determine pesticide labels, does not usually make pesticide application decisions, but the Agency must consider such choices in benefit-cost analyses relating to regulatory decisions. Thus, the EPA benefit-cost analysis must involve an approach whereby alternative decisions are carefully defined based on probable alternative actions of pesticide users.

One kind of probable alternative action of farmers would be the shift to greater use of existing pesticides. For any pesticide presently registered, a gradually increasing use is likely, due to (1) gradually increasing immunity of other pesticides, and (2) a need for each farmer to maximize his management indicators, usually yield per acre per dollar. The first condition has been discussed above and in Volume I of the report. The second condition arises from a complex system of variables in the overall world agricultural context which will not be explained in this report.* The gradual shift to greater use of existing pesticides could thus occur either as a consequence of an EPA denial

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*See, for example, N. S. Scrimshaw, "The Worldwide Confrontation of Population and Food Supply," Technology Review, Vol. 77, 1974, pp. 20-29; and R. Revelle, "Food and Population," Scientific American, September, 1974, pp. 160-171.

of a new registration, or as a consequence of newly registered pesticides entering the market at high prices or with unproven efficacy.

The benefit-cost methodology developed in this report is capable of providing comparisons among the various types of farmer reactions discussed above and caused by either registration, or denial of, registration, of a new pesticide. This capability is illustrated in the case study by assuming that if Fenox is not registered, its next best alternative "Delta" (also an hypothetical phenoxy herbicide which is presently used) will be continued to be used. This alternative was chosen as it is a probable alternative action of farmers.

Thus, even though the role of EPA is not to compare the agricultural implications of alternative pesticides, the EPA benefit-cost system requires this capability. Such comparative analyses are required in any case in which alternative regulatory actions contemplated by EPA would place some farmers in the position of making an immediate choice between two pesticides having different environmental effects and implications.

In summary, this introductory section has established the rationale for using benefit-cost analysis as a strategy for comparing alternative actions available to EPA decision-makers, and by direct connection, alternative actions by farmers, and other users of pesticides. The basic assumptions that farmers will have a variety of reactions available to any EPA action, and that any new pesticide will be used on some proportion of acres previously treated by older pesticides, were discussed.

In Chapter 2.0 of this volume, a summary of the agricultural impacts, health effects, and environmental impacts is presented under the assumption that Fenox is registered for a five-year period and substituted for Delta. A critique of the application procedures of the benefit-cost system is also provided. Later chapters of this volume deal with specific detailed analyses, i.e.:

- Chapter 3.0 -- Agricultural Impacts: A brief description of the model and a sample application which analyzes the use of Fenox and its alternative Delta on wheat, oats, and barley is presented.

- Chapter 5.0 -- Environmental Impacts: A description of the filtering of Fenox and Delta through the environment is given, and the probable net effects on selected higher order species, if Fenox is substituted for Delta, are explored.

Finally, an appendix has been included which illustrates an adaptation of the food, feed, and fiber production submodel of the benefit-cost system for retrospective analysis. The following question is posed: What has been the economic impact on sweet potato, sweet corn, and peanut production since EPA banned DDT in 1972? The benefit-cost system uses data from the period 1969 to 1973 to estimate the 1973 and 1974 economic impacts on production of these three crops.

2.0 SUMMARY OF RESULTS

In this chapter, the detailed results generated in the following three chapters for the phenoxy herbicide case study are summarized. This summary is presented in four sections: agricultural impacts, health effects, environmental impacts, and net benefits. Furthermore, in the last section of this chapter, a critique and feasibility of the benefit-cost system, described in Volume I and applied in Volume II, is provided.

However, before these results are presented, some general information concerning the structuring of the case study must first be discussed, so that the results can be adequately understood.

2.1 General Information Concerning the Structure of the Case Study

As indicated in Chapter 1.0, the analysis performed in the case study assumes that a company wishes to register an hypothetical phenoxy herbicide, Fenox, for use on wheat, oats, and barley crops. Furthermore, the next best alternative to Fenox is defined as Delta, another hypothetical phenoxy herbicide that is presently being used on wheat, oats, and barley crops. The characteristics of both pesticides are assumed to be given by any data of record on the presently registered phenoxy herbicides, i.e., 2,4-D; 2,4,5-T; MCPA; and Silvex. In addition, both pesticides are assumed to have the same characteristics, except in the following respects:

- The increased yield on each of the three crops with Fenox is assumed to be double the increased yield with Delta, when both are compared to the yield obtained using no pesticide.
- The total cost of application for Fenox is assumed to be five percent higher than it is for Delta.
- The ocular and dermal exposure hazards of Fenox are assumed to be approximately 2 and 1.5 times, respectively, the ocular and dermal exposure hazards of Delta.

> **The toxicity of Fenox to birds and fish is assumed to be twice the toxicity of Delta to birds and fish (i.e., the LD_{50}, LC_{50}, etc., of Fenox is one-half the LD_{50}, LC_{50}, etc., of Delta).**

The period of analysis is defined as five years, the period of a pesticide product registration. The year 1973 is used as a base year, as this year is the most recent year for which much of the necessary data are published, and 1974 through 1978 is the five-year period studied. Where monetary evaluations are made, each year's value is first determined, then discounted back to its value in 1974, and finally added together to obtain a five-year discounted total value.

Moreover, the results presented below show the additional benefits and costs of Fenox when compared to its next best alternative Delta. That is, the analysis assumes that if Fenox is not registered, its next best alternative Delta will be continued to be used.

2.2 Agricultural Impacts

Assuming that Fenox receives an EPA registration for use on wheat, oats, and barley crops, it is expected that one-half of the total wheat, oats, and barley acres treated with phenoxy herbicides (i.e., Delta) will be treated with Fenox. This implies that during the five-year period, 1974-1978, 3.04-3.47 million acres of wheat, 0.70-0.79 million acres of oats, and 1.78-2.04 million acres of barley will be treated with Fenox rather than Delta in each of the five years, with the trend over the five years going from the low number in the range to the high number in the range.

Based upon application rates of 0.90 lb/acre/year of Fenox or Delta for wheat, 0.20 lb/acre/year of Fenox or Delta for oats, and 0.46 lb/acre/year of Fenox or Delta for barley, it is expected that 3.4 million pounds and 3.9 million pounds of Fenox rather than Delta will be applied in 1974 and 1978, respectively, with a gradual increase from 3.4 million pounds to 3.9 million pounds during the interim years. Associated with the substitution of Delta with Fenox on the three crops are additional pesticide application costs, and the five-year total additional cost when discounted back to 1974 is estimated at 5.3 million dollars to the farmer.

Furthermore, associated with the application of Fenox, rather than Delta to selected wheat, oats, and barley crops, is an increase in their respective yields. More specifically, it is expected that if Fenox is substituted for Delta, an additional 23.3 million bushels of wheat, 33.2 million bushels of oats, and 10.6 million bushels of barley would have been produced in 1974. In 1978, these figures are expected to be an additional 26.6 million bushels of wheat, 38.2 million bushels of oats, and 12.1 million bushels of barley, if Fenox is substituted for Delta. For the years 1975 through 1977, it is expected that these additional yields will gradually increase from the 1974 additional yields to the 1978 additional yields.

Due to these yield increases, crop prices would have been expected to decrease in 1974 by 1.99 percent for wheat, 6.12 percent for oats, and 3.24 percent for barley. In 1978, it is expected that these price decreases will be 2.19 percent for wheat, 5.96 percent for oats, and 3.33 percent for barley. For the years 1975 through 1977, the price decreases are expected to be within the range specified by the 1974 and 1978 figures.*

The increased total crop output and the decreased crop prices, in each year over the five-year period as a result of substituting Fenox for Delta, will affect the farmers' revenue for these three crops. More specifically, it is expected that the farmers' revenue for these three crops over the five-year period 1974 through 1978 will decrease by a total amount of 141.8 million dollars when discounted back to 1974. This measure, however, gives no indication of the change in the farmers' profit as a result of substituting Fenox for Delta. Assuming the farmer can reduce his total cost of crop production (of which one small element is pesticide application cost) by sufficiently more than the decrease in his revenue, he will increase his total profit by using Fenox rather than Delta. Determination of these effects can provide an understanding of some of the distributional impacts to the farmer associated with the registration of Fenox.

The agricultural impacts described above (i.e., the increased yields and the decreased crop prices, in each year over the five-year period as a result of substituting Fenox for Delta) will also produce a

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*These changes in crop prices do not incorporate the effect of increased pesticide application costs, but rather only the increased yields in the three crops.

net internal benefit to society -- i.e., a change in consumers' surplus. The discounted value in 1974 of this net internal benefit is estimated at 564.1 million dollars for the years 1974 through 1978, if Fenox is substituted for Delta.

2.3 Health Effects

If Fenox is registered for use on wheat, oats, and barley crops and substituted for Delta, the following subpopulation groups are expected to incur additional health damages as a result of this substitution:

- Pesticide R and D, manufacturing, and formulation workers,
- Field workers and other farm personnel, and
- Commercial farm applicators.

Society as a whole is also at risk to additional health damage in an indirect manner, either from drift of Fenox rather than Delta as a result of misuse or accidental spills or from low-level dietary intake of Fenox rather than Delta. However, the defined characteristics of the two hypothetical phenoxy herbicides, the human experience data for parallel pesticides to Delta and Fenox, and the animal toxicology data for the two pesticides, indicate that Fenox or Delta would be in such a dilute form that the likelihood is minimal that drift of Fenox rather than Delta would cause additional harm to society. Furthermore, the dietary intake of both Fenox and Delta is determined to be sufficiently close to zero and the available data give no indication of additional damage, if Fenox is substituted for Delta. Therefore, no additional health damages are expected to occur to society if Fenox is substituted for Delta.

Therefore, only those occupationally exposed are expected to incur any additional health damage if Fenox is substituted for Delta. Results show that the additional health damages will be only ocular and dermal in nature, with the highest net incidence of health damage incurring in the manufacturing and formulating subpopulation and the lowest net incidence of health damage occurring in the commercial farm applicator subpopulation, as shown in Exhibit 2.1.

EXHIBIT 2.1: Net Incidence of Health Damages from Substitution of Delta with Fenox on Wheat, Oats, and Barley Crops (Given as number per 1,000 exposed)

Entity Incurring Health Damage	Type of Health Damage										
	Acute Injury						Chronic Injury				
	Morbidity										
	Ocular Exposure Hazard	Dermal Exposure Hazard	Oral Exposure Hazard	Inhalation Exposure Hazard	Systemic Poisoning	Mortality (Death)	Mutagenic Hazard	Terato-genic Hazard	Oncogenic* Hazard	Reproductive Impairment	Physiologic Malfunction Hazard*
Occupational Health Damage to:											
Pesticide R&D Manufacturing and Formulation Workers	96	52	0	0	0	0	0	0	0	0	0
Pesticide Transport Personnel		Not determined but assumed to be negligible based on discussions with OPP personnel									
Field Workers and Other Farm Personnel	10.5	4.1	0	0	0	0	0	0	0	0	0
Commercial Farm Applicators	0.47	0.18	0	0	0	0	0	0	0	0	0
Professional Non-Farm Applicators (FCO's, government employees, etc.)	na	na	na	na	na	na	na	na	na	na	na
General Public Health Damage to: Household Users of Pesticides (through direct exposure)	na	na	na	na	na	na	na	na	na	na	na
Society as a Whole (through indirect exposure)	0	0	0	0	0	0	0	0	0	0	0

na = not applicable

*In particular, with respect to central nervous system, hematopoetic system, liver and kidneys.

When these incidence rates are coupled with the number of people in each subpopulation group expected to be exposed in each of the five years 1974 through 1978, field workers and other farm personnel are expected to incur the most additional health damage and commercial farm applicators the least, in terms of absolute numbers, as shown in Exhibit 2.2.

Quantification of these additional health damages, although desirable if possible, was not performed. More detailed information concerning the characteristics of the people injured would be needed for such an analysis. However, these data could not be easily obtained in sufficient detail to warrant such an analysis in this case study. Nevertheless, in benefit-cost analyses of real pesticides, attempts should be made to make such a quantification as this information can prove very useful to the decision-maker. In this case study, it was demonstrated in the detailed analysis of health effects (Chapter 4.0) that because the additional health damages are occupational in nature, the costs of these damages are partially embodied in the change in the consumers' surplus measure determined in the agricultural impacts analysis.

Health benefits from the use of Fenox, if substituted for Delta, will accrue to society in the form of a more healthful, more productive, and more content population, as a result of an increased food supply caused by the increased yields in the three crops described earlier in Section 2.2. Once again, quantification of these additional health benefits, although desirable if possible, was not performed. However, in the detailed analysis of health effects (Chapter 4.0), it was demonstrated that the additional health benefits that do accrue to society are reflected in the change in the consumers' surplus measure determined in the agricultural impacts analysis.

2.4 Environmental Impacts

In the assessment of the net environmental impacts on society associated with the substitution of Fenox for Delta on wheat, oats, and barley crops, non-crop environmental benefits were assumed to be minor or negligible. However, environmental costs are of concern because, subsequent to the application of Fenox or Delta on wheat, oats, and barley crops, some of the pesticide is transported away from the application site where it accumulates in biological organisms such as birds and fish.

EXHIBIT 2.2: Number of Additional People Expected to Incur Health Damage from Substitution of Delta with Fenox on Wheat, Oats, and Barley Crops (Given as number per year for 1974-1978)

Entity Incurring Health Damage	Type of Health Damage										
	Acute Injury						Chronic Injury				
	Morbidity										
	Ocular Exposure Hazard	Dermal Exposure Hazard	Oral Exposure Hazard	Inhalation Exposure Hazard	Systemic Poisoning	Mortality (Death)	Mutagenic Hazard	Terato-genic Hazard	Oncogenic* Hazard	Reproduc-tive Im-pairment	Physiologic Malfunction Hazard*
Occupational Health Damage to:											
Pesticide R&D Manufacturing and Formulation Workers	5-7	3-4	0	0	0	0	0	0	0	0	0
Pesticide Transport Personnel		Not determined but assumed to be negligible based on discussions with OPP personnel									
Field Workers and Other Farm Personnel	373-374	146-147	0	0	0	0	0	0	0	0	0
Commercial Farm Applicators	1-2	0-1	0	0	0	0	0	0	0	0	0
Professional Non-Farm Applicators (FCO's, government employees, etc.)	na	na	na	na	na	na	na	na	na	na	na
General Public Health Damage to: Household Users of Pesticides (through direct exposure)	na	na	na	na	na	na	na	na	na	na	na
Society as a Whole (through indirect exposure)	0	0	0	0	0	0	0	0	0	0	0

na = not applicable

*In particular, with respect to central nervous system, hematopoetic system, liver and kidneys.

180<

The environmental analysis assumed that based upon the application rates for Fenox or Delta on the three crops, and other defined characteristics of the two hypothetical herbicides, the amount of either pesticide accumulated in fish and birds would be similar. However, the effect of this accumulation will be different because Fenox is defined to be more toxic than Delta to birds and fish. More specifically, if Fenox is substituted for Delta, it is expected that during the five-year registration period of 1974 through 1978, the number of additional birds killed will be approximately 2.5 million. For fish, it is expected that an additional 154 million will be either killed or not produced during the five year registration period. These numbers correspond to a total discounted value in 1974 of 10.7 million dollars for fish and bird damages for the five year registration period. It should be emphasized that this value of additional environmental damage is an underestimate due to the lack of total costs for restocking and due to the lack of estimates of additional mammals, including both small and large game, lost due to accumulation of Fenox rather than Delta in the food chain.

2.5 Net Benefits from Use of Fenox When Substituted for Delta

The net benefits to society from the use of Fenox when it is substituted for Delta consist of the net internal benefit plus the net external benefit of using Fenox if substituted for Delta.

It has been determined in Section 2.2 that the discounted value in 1974, of the net internal benefit to society, associated with the substitution of Delta with Fenox on wheat, oats, and barley crops, is equal to 564.1 million dollars for the five year registration period 1974 through 1978. Furthermore, it has been stated that the additional health benefits received by society during this time period are embodied in this measurement, but that the additional health costs incurred by the occupationally exposed during this time period are only partially embodied in this measurement.

In addition, not embodied at all in this measurement are the additional pesticide application costs to the farmer when Fenox is substituted for Delta. The reason for this is that the crop price forecasting algorithm used in the case study did not incorporate increased pesticide application cost factors. Therefore, the additional pesticide application costs of 5.3 million dollars for the five years when discounted back to 1974 must, in this instance, be subtracted from the net internal benefit.*

The net external benefit to society associated with the substitution of Delta with Fenox consist of additional external costs and thus is negative. The major external costs consist of the additional environmental damages caused if Fenox is substituted for Delta. They have been estimated at 10.7 million dollars for the five-year registration period when discounted back to 1974. Additional external costs that are not quantified consist of additional occupational health costs not embodied in the consumers' surplus measure, as well as undetermined restocking costs and costs for additional mammals lost.

Therefore, the five-year net benefits to society (discounted back to 1974) associated with the substitution of Fenox for Delta on wheat, oats, and barley crops can be estimated as: 564.1 million dollars - 5.3 million dollars - 10.7 million dollars = 540.1 million dollars. Emphasis must be made that these net benefits are an overestimate as the value of the net external benefit (or more specifically, external costs) has not been fully quantified in monetary terms. Nevertheless, it does appear that the registration of Fenox for use on wheat, oats, and barley will provide substantial net benefits to society when compared to its next best alternative Delta. Distributional impacts may favor some subpopulations and injure others. However, an adequate determination of these impacts has not been made and therefore cannot be put into a matrix form for viewing by the decision-maker.

2.6 Critique and Feasibility of the Benefit-Cost System

2.6.1 Difficulties in the Submodel Approach

The purpose of this section is to critique the procedures applied and the results obtained in the three detailed submodel chapters 3.0, 4.0, and 5.0. As noted in the Introduction, the benefit-cost system is applied in the format of three submodels, although additional submodels

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*In most analyses, these costs will be embodied in the consumers' surplus measure and will serve only to indicate distributional impacts.

may be needed in other case applications. The three submodels applied in the reported case study are the food, feed, and fiber production submodel, the health effects submodel, and the environmental effects submodel. Each of these submodels has within it a series of algorithms (i.e., sub-submodels) which are intended to be reasonably standard for more than one benefit-cost analysis, and hopefully, for many such analyses.

In other words, the present benefit-cost system attempts to do what many benefit-cost methodologies attempt to do, usually without a great deal of success: standardize and format a benefit-cost procedure which will be reasonably applicable over a series of pesticide benefit-cost applications, providing both flexibility, as well as a standard, simplified set of procedures in the same overall system. One approach to the standardization of the system is the identification of broad submodels which provide general headings under which to group algorithms which typically draw on the same data sources. For example, under the food, feed, and fiber production submodel, there are grouped algorithms for calculating acreages of crops harvested in future years, those acreages of these crops to which a given type of pesticide is likely to be applied, and changes in yield of those acreages where the pesticide was applied.

These different algorithms all require input data from time series agricultural data sets, although different forecast studies and documents may be available for selection and use in any given benefit-cost application. Where such choices exist, an attempt has been made to document them and to explain the reason for the choice which was made. In addition to the time series acreage data, several algorithms require farm management data on pesticide application acreage and rates per acre. Thus, algorithms which require similar input data are grouped into the same submodel, since their inputs and outputs are usually linked.

Thus, the algorithms applied in each of the submodels are directed toward the calculation of benefits and costs which are specific to the general heading of the submodel. The health effects submodel, for example, calculates health costs arising from health damages due to the dispersal of pesticides through the environment. This same submodel would also be used to calculate health benefits arising from the use of a public health pesticide effort (e.g., rodenticide use, mosquito control, cockroach control). In the typical agricultural pesticide use situtation, however, there are no easily defined health benefits, and a detailed analysis of health benefits is not shown in the present case example. But such benefit calculations would use data on populations exposed, probabilities of illness, and severity of reaction to disease, similar to the data used in the health damages calculations presented in this report.

This lack of development of certain selected submodel components, such as health benefits, along with the previously mentioned difficulties associated with devising both a flexible, broadly applicable system and also a simple, standardized set of procedures, are probably the most prominent criticisms of the system as developed in the present report. The lack of development of certain submodel components is not a severe criticism because neither in a limited system development effort, nor in a specific case study, should there arise the expectation that all conceivable sub-analyses would be explicated. Nevertheless, the reader is left with the vague discomfort that surely some portion of a benefit or cost to some subpopulation has gone unquantified. The problem arises because the comprehensive, fully extensive structure of the benefit-cost matrix is not applicable in every case study, and yet those components which are not applicable tend to raise the question, "Wasn't something left out?"

Similarly, the reader does not see displayed before him a completely symmetrical accounting system, in which every cost leads directly to some benefit, which enables the ready calculation of a series of net benefits. A natural response is to question whether the achievement of some particular benefit contributes "substantially" to any particular costs. If, for example, the farmer applies 1.1 pounds per acre of Fenox, instead of 0.9 pounds per acre, he probably achieves a higher yield for a two or three season period. Does the increment of additional pesticide "really" have any increased impact on the environment? These are detailed accounting questions which the system can answer, but only through successive iterations of large numbers of calculations. Similarly, which component of the benefits from increased yield is the component which corresponds directly to some proportion of fish population lost? This correspondence is another kind of symmetry which is rarely attainable.

2.6.2 Difficulties in Formatting Results

The above points lead to the problem of formatting results. The formatting problem is serious in most benefit-cost analyses, and reflects the difficulty not only of what kinds of final ratios or net values to select as sophisticated indicators, but also of the design of graphic or tabular displays. Typically, the decision-makers who expect a lot from benefit-cost analysis are seeking a final summary of results in some type of accounting format where various component costs are clearly connected to the "corresponding" benefits, and the final net values or ratios clearly distinguish among the alternative actions. People who work on the actual conduct of benefit-cost analyses find this kind of final summary difficult to achieve, both technically and ethically.

Such a summary is difficult to achieve technically because of the dynamic, sequential nature of events which are modeled and analyzed in a benefit-cost study. The specific benefits and costs occur over long periods of time, in quasi-causal sequences, the various items "dropping out" occasionally as the natural sequence of events evolve. Nowhere is this more true than in the development of ecologic damages and costs, where increases in costs of maintaining wildlife populations occur sporadically as pesticide residues accumulate biologically and add complexity to the ongoing population cycles of various species. The application of the environmental effects submodel in this report illustrates a way to depict each type of cost or damage as it occurs in the natural sequence of impacts, but a final summary table is not achieved.

If such a table were derived, showing damages to water quality, fish, and higher species, it would cause some confusion, and would raise ethical questions about its derivation, since none of the damages and costs would be "independent" in the sense that they arose separately from the initial action of pesticide application. All of these successive costs probably would be avoided if an alternative action were taken which did not include the registration of the pesticide (e.g., Fenox). But they do not necessarily impinge on society as separately measured, non-overlapping costs.

In other words, is the aesthetic cost of a reduction in stream or lake water quality the same or a different cost from that of replacing the fish in that same lake or stream -- after all, the fish die for the same reason that the water stinks? Thus, summation of these costs might not be justifiable, and therefore, they are not presented in a table form in the final summary, but rather in a series of concise paragraphs. But even this less than hard facts approach suffers from an inability to convey adequate warning to the decision-maker, which, if added in the form of caveats, could produce a presentation which loses sight of the essential information and also loses any trace of conciseness and simplicity of formatting.

2.6.3 Difficulties in Obtaining Input Data

One of the most severe data problems appears almost at the outset of the benefit-cost system, i.e., in the initial stages of the agricultural submodel. This is the problem of determining the quantities of specific pesticides used on specific crops. There are actually four variables of interest:

- Pesticide used,
- Amount applied,
- Crop treated, and
- Number of acres treated.

In addition, it would be desirable to know the number of applications per season, the time of each application, the amount applied each time, and whether the method was aerial, surface or soil injection.

Having comprehensive data, in some reasonable geographic detail, of the type defined above would put a completely different light on the conduct of the type of benefit-cost system described in this report. Calculations in the agricultural submodel would become much more realistic and convenient, and the assessment of subpopulation effects in the health effects submodel would also improve. The environmental effects submodel would be able to reflect seasonal timing of impacts, and would be able to reflect the different effects arising from different types of application.

The only source of these data available to date has been the two surveys conducted by the U. S. Department of Agriculture, Economic Research Service, in 1966 and 1971.* This effort is continuing and hopefully more recent data will soon be available. The results published in reports of the two previous surveys did not contain data in geographic detail below the regional level, and data on numbers of applications per season and type of application method were not given. Hopefully, the reports of new surveys will have the desired detail. This is a good place to re-emphasize that the usefulness of a pesticide benefit-cost system is going to depend heavily on its accessibility and

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*Eichers, T., Quantities of Pesticides Used by Farmers in 1966, Agricultural Economics Report No. 179, 1970, pp. 42-44; and P. A. Andrilenas, Farmers' Use of Pesticides in 1971: Quantities, USDA, ERS, Agricultural Economics Report No. 252, 1974.

operability by a large number and a large variety of people, agencies, and firms. If the system has to depend on data collected in special surveys (i.e., data not widely available), then the results of analyses performed using the system will never gain credibility, and will never be acceptable as factors in regulatory decisions.

A second type of data which is not available and which will present a problem to the system user is the type of data needed to answer the question of long-term effects on human health from small amounts of pesticides in the human body. Although data derived from toxicological studies of laboratory animals has gained increasing acceptance as the basis for estimates of incidences of various diseases in people, it is time to start developing some alternatives to the laboratory animal techniques. These new approaches should involve the combining of results from both epidemiological studies of certain ailments, and also statistical studies of the type which Lester Lave has conducted on the probabilities of people with certain diseases having been exposed to certain levels of air pollution in their environments.* In addition to these types of studies, a third type of study in the medical field would be useful, wherein the mechanisms by which small amounts of certain classes of molecules in the human body engender certain diseases or malfunctions are explored. At present, work is in progress on all three types of studies, but the outlook for early success is uncertain. As data become available from these three types of studies, these data should be integrated into the health effects submodel.

Problems in the use of the environmental effects submodel arise not only from lack of data on impacts and effects, but also from lack of data on values of wildlife and aesthetic features of the environment. Nevertheless, what is most lacking in the environmental effects submodel are some comprehensive, detailed formulations for expressing the routes and mechanisms of impingement of pesticides on wildlife. A standard model for describing pesticide drift from aerial spraying should be obtained, plus models for runoff from cropland into lakes and streams.

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*Lave, Lester B., and Eugene P. Seskin, "Air Pollution and Human Health," Science, Vol. 169, No. 3947, August 21, 1970, pp. 723-733.

2.6.4 Difficulties in the Conceptual Design of the Benefit-Cost System

Several conceptual issues continue to exist in the benefit-cost system, and they were not completely resolved in the case study. Therefore, numerous assumptions had to be made, and they are presented and explained in the detailed analyses in Chapters 3.0, 4.0, and 5.0. Thus, a series of conceptual reviews of the system will be necessary as better data is developed, so that the assumptions made can be refined, based upon the most recent knowledge available.

3.0 AGRICULTURAL IMPACTS

3.1 Net Internal Benefits to Society

The analysis presented in the food, feed, and fiber production submodel of Volume I of the report has generated the conclusion that the value of the net internal benefit attributable to an increase in yield of an agricultural crop is appropriately measured by the change in consumers' surplus which is produced by this yield increase. Moreover, this analysis asserts that this change in consumers' surplus, attributable to the application of Fenox rather than Delta, can be approximated reasonably by:

$$\Delta CS_{jt} = \Delta P_{jt} \cdot Q_{j,t-1} + 1/2 \cdot \Delta P_{jt} \cdot \Delta Q_{jt}$$

where: ΔCS_{jt} = the estimated change in consumers' surplus attributable to the application of Fenox to crop j in year t, when compared to its next best alternative Delta,

ΔP_{jt} = the net change in the price of one unit of crop j attributable to the application of Fenox in year t, when compared to its next best alternative Delta,

$Q_{j,t-1}$ = the total output of crop j in year (t-1), and

ΔQ_{jt} = the net change in the total output of crop j in the nation attributable to the application of Fenox in year t, when compared to its next best alternative Delta.

Three crops were chosen for analysis -- wheat, oats, and barley. These were selected as important economically and as representative of a broad use of herbicides, i.e., a demand which is not presently filled by any one herbicide and which is not characterized by any one weed. Furthermore, as indicated above, two hypothetical phenoxy herbicides are being compared -- Fenox which is being proposed for registration and Delta which is defined as its next best alternative.

The agricultural characteristics of Fenox and Delta are based upon any data of record on phenoxy herbicides and are similar in all respects, except for their respective increased yields per acre for the same application rate when compared to no pesticide and their respective costs of application.

A five-year period, beginning with 1974 and ending with 1978, was selected for analysis. The year 1974 was chosen because this was the year in which the study began and 1978 was chosen because it is five years later, the period of registration for any pesticide. However, 1973 was also chosen as the base year because it is the most recent year for which production data are available.

Throughout much of the analysis, data for only two years -- 1973 and 1978 -- are presented. However, in the determination of the change in the consumers' surplus measure for 1974 through 1978, values for 1974 through 1977 are also presented and then discounted back, along with the 1978 value, to their value in 1974. A more accurate and desirable procedure is to interpolate the data for 1974 through 1977 at each step in the determination of the consumers' surplus measure. However, because this case study is an exercise in showing the applicability of the methodology using an hypothetical phenoxy herbicide, these increased calculations were felt to add little to the presentation. Therefore, the "short-cut" procedure, as indicated above, was used.

In the determination of ΔCS_{jt} defined above, five year forecasts of Q_j require calculation, but published sources of large-scale data may be used.* The calculations of ΔQ_{jt} and ΔP_{jt} require substantially more data manipulation. These manipulations are described in detail in the following sections.

3.1.1 Acres of Crops Treated with Fenox

The first step in arriving at the net internal benefits is to calculate the number of acres of the crops mentioned which were treated by herbicides during the production years named. Later, it will be necessary to determine the change in yield of the crop which results from the use of the herbicide.

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*For example, see Agricultural Statistics and the Census of Agriculture.

The number of acres of any particular crop which are treated with a pesticide varies with the observations of infestation (insects, weeds) by the farmer and with his hopes and expectations of a good yield. Because of data limitations, it is necessary to perform calculations which allocate the number of acres treated by all herbicides among the acres of a specific crop treated by a specific herbicide. Proportional allocating factors can be obtained as shown in Exhibit 3.1, which gives the results of applying the formula:

$$FC_j = TCA_j/TA,$$

which calculates the proportion of acres of a specific crop j, to which all herbicides have been applied.

The results shown in Exhibit 3.1 can be used to estimate the actual numbers of acres, based on the corresponding proportion of crop j, a specific crop, to which all herbicides have been applied in year t. These calculations are shown in Exhibit 3.2. The variable "specific crop acres treated by herbicides" is calculated by applying the proportion FC_j, as derived in Exhibit 3.1, to the acres of all crops treated by herbicides, to obtain the number of acres treated by all herbicides for:

- Wheat, and
- Other grains.

The basic data on acres of all crops treated by herbicides are obtained from the Census of Agriculture,* but the proportions for crops, as well as for regions, are obtained from the USDA survey.**

If, however, the number of acres treated of crop j are actually acres of a crop category which is more aggregate than the crop under consideration in the pesticide registration process, additional disaggregation can be performed by using data on acres harvested from Agricultural Statistics, an annual publication of the U. S. Department of Agriculture.

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*U. S. Bureau of the Census, Department of Commerce, Census of Agriculture, 1969, data reproduced in D. L. Fowler and J. N. Mahan, Pesticide Review, 1972, USDA, Stabilization and Conservation Service, 1972, p. 35.

**Cited in Exhibit 3.1.

EXHIBIT 3.1: Calculation of the Proportion of Total Acres of crop j Treated With Herbicides Where j = wheat; other grains*

	j = wheat		j = other grains	
	1966 Acres	1971 Acres	1966 Acres	1971 Acres
TCA_j**	16,660,000	25,584,000	10,163,000	12,517,000
TA**	112,455,000	213,652,000	112,455,000	213,652,000
FC_j***	0.04815	0.11975	0.09037	0.05859
Average FC_j****	0.083950		0.074480	

*"Other grains" includes oats, mixed grains, barley, and rye.

**TCA_j = total crop acres treated by all herbicides, crop j, and
TA total acres of all crops treated by all herbicides.

***FC_j $= TCA_j/TA = \left(\frac{\text{Acres of crop j treated}}{\text{Total acres treated}}\right)$

****Although the two years data for wheat and other grains show shifts in the proportion FC_j, it was not felt that a trend could be indicated by such limited data. Therefore, an average of the two years data was felt to provide a more reliable estimate.

Sources: T. Eichers, Quantities of Pesticides Used by Farmers in 1966, Agricultural Economics Report No. 179, 1970, pp. 42-44; and P. A. Andrilenas, Farmers' Use of Pesticides in 1971: Quantities, USDA, ERS, Agricultural Economics Report No. 252, 1974.

EXHIBIT 3.2: Calculation of Acres Treated with All Herbicides for Selected Years, Regional Shares (TCA_{jkt})
(Acres in thousands)

	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta States	South-ern Plains	Moun-tain	Pacific	United States Total
1971											
All crop acres treated with herbicides (regional proportions)*	.02802	.11870	.31382	.18660	.04414	.04049	.09639	.06563	.05577	.05044	1.00000
1973											
All crop acres treated with herbicides	2,241	9,494	25,000	14,925	3,530	3,239	7,710	5,249	4,461	4,034	79,982**
Wheat acres treated with herbicides (0.08395 of all crop acres)	188	797	2,099	1,253	296	272	647	441	375	339	6,714
Other grain acres treated with herbicides (0.07448 of all crop acres)	167	707	1,862	1,112	263	241	574	391	332	301	5,957
1978											
All crop acres treated with herbicides	2,636	11,169	29,528	17,557	4,153	3,810	9,069	6,175	5,248	4,746	94,091**
Wheat acres treated with herbicides (0.08395 of all crop acres)	221	938	2,479	1,474	349	320	761	518	441	398	7,900
Other grain acres treated with herbicides (0.07448 of all crop acres)	196	832	2,199	1,308	309	284	676	460	391	354	7,008

*Proportions calculated from data in P. A. Andrilenas, op. cit., 1974, Appendix Table 10, pp. 40-41. (Used to allocate United States total acres to regional total acres in 1973 and 1978.)

**See Exhibit 3.5.

In the present case study of a fabricated hypothetical phenoxy herbicide Fenox, it was necessary to disaggregate the crop category "other grains" to acres for barley and acres for oats (see Exhibit 3.3). The acres for wheat treated by herbicides were available directly from USDA surveys, as shown in Exhibit 3.2, and the final results for the three specific crops -- wheat, oats, and barley -- are shown in Exhibit 3.4. The data for the year 1978 are all obtained by factors shown in Exhibit 3.5. In other words, acres harvested were readily available for 1973, so that the proportions within the category "other grains" could be determined. These proportions (FC'_{mj}) were then applied to acres treated as shown in Exhibit 3.2 to obtain the acres treated as shown in Exhibit 3.4. Since these data were only for 1973, it was necessary to forecast through 1978 using the published forecasts cited in Exhibit 3.5.

It is now necessary to estimate the proportion of these acres treated by herbicides which were, and which will be, treated by the hypothetical herbicide Fenox. Using the formula shown in Exhibit 3.6, proportional factors can be obtained from USDA survey data. Since the herbicide Fenox under consideration is hypothetical, hypothetical values for FDijmt, as shown in Exhibit 3.7, can be used. These factors determine the total expected usage, or market penetration factor, if Fenox were to be registered. As indicated by the factors chosen, it is hypothetically assumed that Fenox, if registered, will be substituted on one-half the acres treated with phenoxy herbicides (i.e., Delta). The final results of applying these factors to the total acres treated (Exhibits 3.4 and 3.5) are shown in Exhibit 3.8.

3.1.2 Net Changes in Crop Yield

The testing of the efficacy of pesticides for improving crop yields in field-like situations is typically conducted on test farms which are operated by experiment stations and other agencies in all parts of the country. If the changes in yield per acre are reported consistently by the experiment stations in some conventional units of weight, then it becomes a relatively simple procedure to calculate the difference which is observed between the yield which is obtained when the proposed new herbicide is applied to a crop and the yield which is obtained when no herbicides are applied to that crop. This also facilitates the comparison with the next best alternative herbicide, Delta, to get a net effect for the herbicide under consideration.

EXHIBIT 3.3: 1973 Acres Harvested for Selected Crops (Thousands)
Calculation of FC'_{mj} (Proportion of acres harvested for a specific crop within a category)

Acres Harvested \ Proportion of Total	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific
(A) Other grains barley, rye, oats (THA_m)*	1,029	5,320	1,707	8,504	451	356	95	1,361	3,965	1,882
(B) Barley (HA_j)	202	938	50	3,534	239	38	---	325	3,506	1,595
$B/A = FC'_{mj}$	.19631	.17632	.02929	.41557	.52993	.19674	.00000	.23880	.88424	.84750
(C) Oats (HA_j)	766	4,250	1,597	4,500	180	169	95	844	439	270
$C/A = FC'_{mj}$	.74441	.30019	.93556	.52916	.39911	.47472	1.00000	.62013	.11072	.14346

*THA_m = acres harvested in a general crop category m; values for barley and oats are HA_j, the acres harvested for specific crops. See USDA, Agricultural Statistics, 1974, tables for barley and oats (Tables 2, 50, and 59, pp. 2, 37, and 43).

EXHIBIT 3.4: Calculation of Acres Treated by All Herbicides for Oats and Barley (TCA_{jkt}) (Acres in thousands)

		Region (k)									
		North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific
Other grains TCA_{mjt}*	1973	167	707	1,862	1,112	263	241	574	391	332	301
	1978	196	832	2,199	1,308	309	284	676	460	391	354
TCA_{jkt} j = barley**	1973	33	125	55	462	139	26	---	93	294	255
	1978	39	147	64	544	164	30	---	110	346	300
TCA_{jkt} j = oats**	1973	124	212	1,742	588	105	114	574	243	37	43
	1978	146	250	2,057	692	123	135	676	285	43	51

*TCA_{mjt} = total acres treated with herbicides in crop category m.

**TCA_{jkt} = $(FC'_{mj})(TCA_{mjt})$

EXHIBIT 3.5: Calculation of Total Acres Treated with Herbicides (TCA_{jkt}) for Wheat, Oats, and Barley, United States Totals

		All Crops (thousands of acres)			Wheat + Oats + Barley (thousands of acres)
Acres Harvested	1964	298,000[1]			80,177[2]
	1969	290,000[1]			75,038[3]
	1971	305,000[1]			---
	1973	322,000[1]			78,512[4]
	1978	378,804[5]			75,430[5]
	1985	458,331[6]			71,114[6]
Acres Treated by Herbicide[7]	1964	60,783[8]	60,783/298,000 = 0.20397	Average 0.24839[10]	16,354[11]
	1969	84,914[9]	84,914/290,000 = 0.29281		21,972[11]
	1971	---			---
	1973	79,982 =	(322,000) · (0.24839)		19,502[11]
	1978	94,091 =	(378,804) · (0.24839)		18,736[11]

[1] USDA, Agricultural Statistics, 1974, Table 625, p. 440.

[2] USDA, Agricultural Statistics, 1966, pp. 2, 39, and 45.

[3] USDA, Agricultural Statistics, 1971, pp. 2, 36, and 42.

[4] USDA, Agricultural Statistics, 1974, pp. 2, 37, and 43.

[5] Interpolated from 1985 data.

[6] Smith, Allen, et al., Projections of the U. S. Farm Subsector and Policy Implications, USDA, 1974, p. 31.

[7] Excludes pasture and rangeland.

[8] U. S. Bureau of the Census, 1964 Census of Agriculture, Vol. II, Chapter 10, Table 11, p. 1054.

[9] Fowler, D. L., and J. N. Mahan, Pesticide Review, 1972, USDA, 1973.

[10] Although the two years data show an upward shift in this proportion, it was not felt that a trend could be indicated by such limited data. Therefore, an average of the two years data was felt to provide a more reliable estimate.

[11] Wheat, oats, and barley acres treated = (total acres treated with herbicides)

$$\times \left(\frac{\text{wheat, oats, and barley acres harvested}}{\text{total acres harvested, all crops}}\right)$$

197<

EXHIBIT 3.6: Acreage in Specific Herbicide Use, 1966-1971 (National data)
$FPC_{ij} = TCPA_{ij}/TCA_j$* (Acres in thousands)

		1966		1971	
		Wheat	Other Grains	Wheat	Other Grains
(A) Total Herbicides (TCA_j)		16,600	10,613	25,584	12,517
(B) 2,4-D	$TCPA_{ij}$ FPC_{ij} (B/A)	13,733 0.82729	8,053 0.75879	19,268 0.75313	7,504 0.59950
(C) MCPA	$TCPA_{ij}$ FPC_{ij} (C/A)	766 0.04614	1,522 0.14341	3,189 0.12465	3,850 0.30758
(D) All Phenoxy	$TCPA_{ij}$ FPC_{ij} (D/A)	14,577 0.87813	9,692 0.91322	22,567 0.88207	11,585 0.92554

*FPC_{ij} = the proportion of the total number of acres of crop j in the nation to which herbicides have been applied which constitute acres to which pesticide i has been applied in the survey year,

$TCPA_{ij}$ = the total number of acres of crop j in the nation to which pesticide i has been applied in the survey year,

TCA_j = the total number of acres of crop j in the nation to which herbicides have been applied during the survey year.

Sources: Eichers, T., *et al.*, *Quantities of Pesticides Used by Farmers in 1966*, USDA, ERS, Agricultural Economics Report No. 179, Washington, D.C., 1974, Table 25, pp. 41-44; and P. A. Andrilenas, *Farmers' Use of Pesticides in 1971: Quantities*, USDA, ERS, Agricultural Economics Report No. 252, Washington, D.C., 1974, Table 9, pp. 36-39.

EXHIBIT 3.7: Calculation of Proportion of Herbicide-Treated Acres on Which the Hypothetical Phenoxy Herbicide Fenox Would Be Used ($\overline{FPC_{ijt}}$)*

		FPC_{mj}		FD_{ijmt}		$(FPC_{mj})(FD_{ijmt})$	
		Wheat	Other Grains	Wheat	Other Grains	Wheat	Other Grains
1973	2,4-D	0.82729	0.75879	0.50	0.50	0.41365	0.37940
	MCPA	0.04614	0.14341	0.50	0.50	0.02307	0.07171
1978	2,4-D	0.75313	0.59950	0.50	0.50	0.37657	0.29975
	MCPA	0.12465	0.30758	0.50	0.50	0.06233	0.15379

$\overline{FPC_{ijt}}$ = 2,4-D + MCPA: 1973 = 0.43672 (wheat); 0.45111 (other grains)
1978 = 0.43890 (wheat); 0.45354 (other grains)

*$\overline{FPC_{ijt}} = (FPC_{mj})(FD_{ijmt})$ where $\overline{FPC_{ijt}}$ = the proportion of the total number of acres of crop j in the nation to which pesticide i will be applied in year t, FPC_{mj} = the proportion of the total number of acres of crop j in the nation to which herbicides have been applied which constitutes acres to which pesticide m has been applied in the survey year (equivalent to FPC_{ij} of Exhibit 3.6), and FD_{ijmt} = the proportion of the total number of acres of crop j in the nation to which pesticide m is applied in the base year and pesticide i is expected to be applied in year t; i = Fenox and m = Delta.

EXHIBIT 3.8: Calculation of Acres Treated with Hypothetical Herbicide Fenox
$TCPA_{ijkt} = (\overline{FPC_{ijt}})(TCA_{jkt})$* (Acres in thousands)

		North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific
1973	Wheat	82	348	917	547	129	119	283	193	164	148
	Barley	15	56	25	208	63	12	--	42	133	115
	Oats	56	96	786	265	47	51	259	110	17	19
	Total	153	500	1,728	1,020	239	182	542	345	314	282
1978	Wheat	97	412	1,088	647	153	141	334	227	194	175
	Barley	18	67	29	247	74	14	--	50	157	136
	Oats	81	113	933	314	56	61	307	129	20	23
	Total	196	592	2,050	1,208	283	216	641	406	371	334

*$TCPA_{ijkt}$ = acres of crop j in region k treated with herbicides i in year t.

TCA_{jkt} = acres treated with all herbicides (see Exhibits 3.2 and 3.4).

$\overline{FPC_{ijt}}$ = estimated proportion of all herbicide-treated acres which are treated with hypothetical herbicide Fenox (see Exhibit 3.7).

The yield difference from the proposed herbicide to its next best alternative can then be applied to the estimated number of acres of the crop treated, in order to obtain the total net change in yield for the specific herbicide, and for the specific weeds. The simplified calculations for total net increased yield are performed according to the formula:

$$\Delta Q_{jkt} = \Delta Y_{jkt} \cdot TCPA_{jkt}$$

where: ΔQ_{jkt} = the net change in the total output of crop j in year t in region k attributable to the application of Fenox, when compared to its next best alternative Delta,

ΔY_{jkt} = the net change in the yield per acre of crop j in region k attributable to the application of Fenox in year t, when compared to the next best alternative Delta, and

$TCPA_{jkt}$ = acres of crop j in region k treated with Fenox in year t.

The values of ΔY_{jkt} used are shown in Exhibit 3.9, along with the reports of experimental tests on which they are based. $TCPA_{jkt}$ has been calculated and is shown in Exhibit 3.8. The total net change in yield from the acres treated with Fenox is shown in Exhibit 3.10 using the above formula.

3.1.3 Net Changes in Crop Prices

Before the benefit which is generated by this net increase in national output can be calculated, it is necessary to estimate the effect that this net change in output will have upon the price of the crop. Since this net increase in output results in a net increase in the supply of the product, the effect upon the price of the crop will be determined by the demand for the crop. More specifically, the reduction in the price of the crop which is caused by this net increase in output is determined by the price elasticity of demand for the crop. This price elasticity is incorporated in the formula shown in Exhibit 3.11, where the previous price, $P_{j,t-1}$, is obtained from Exhibit 3.12.

EXHIBIT 3.9: Net Change in Yield Per Acre Due to Use of Fenox Rather Than Delta

	Delta* (Over No Herbicide)	Fenox** (Over No Herbicide)	Net Change in Yield (Fenox Over Delta)
Wheat (bu/acre)	7.67	15.34	7.67
Application rate per treatment per acre (in lbs)	0.45	0.45	0.45
Barley (bu/acre)	15.27	30.54	15.27
Application rate per treatment per acre (in lbs)	0.23	0.23	0.23
Oats (bu/acre)	18.75	37.50	18.75
Application rate per treatment per acre (in lbs)	0.10	0.10	0.10

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*Source:

For wheat: Blackman, G. E., and H. A. Roberts, "Studies in Selective Weed Control," The Journal of Agricultural Science, Vol. 40, 1950, Table 2, p. 64. SMCP compared with control (data for 1944).

For barley: Blackman, G. E., and H. A. Roberts, op. cit., average of four results compared with control, Tables 7 and 8, pp. 76-77 (data for 1944-1945).

For oats: Blackman, G. E., and H. A. Roberts, op. cit., average of two results compared with control, Table 3, p. 72 (data for 1945).

**Because Fenox is an hypothetical herbicide, its yield over using no pesticide is hypothetically assumed to be two times the yield with Delta. Test plot data have indicated that two similar type pesticides can have such a large difference in yield and thus this assumption, although hypothetical, has been shown to be the case in some instances with real pesticides.

EXHIBIT 3.10: Net Change in Yield Due to Use of Fenox Rather Than Delta (Bushels in thousands)

		Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta	Southern Plains	Mountain	Pacific	United States Total
Wheat	1973	629	2,669	7,033	4,196	989	913	2,171	1,480	1,258	1,135	22,473
	1978	744	3,160	8,345	4,963	1,174	1,082	2,562	1,741	1,488	1,342	26,601
Barley	1973	229	855	382	3,176	962	183	---	641	2,031	1,756	10,215
	1978	275	1,023	443	3,772	1,130	214	---	764	2,397	2,077	12,095
Oats	1973	1,050	1,800	14,738	4,969	881	956	4,856	2,063	319	356	31,988
	1978	1,519	2,119	17,494	5,888	1,050	1,144	5,756	2,419	375	431	38,195

EXHIBIT 3.11: Calculation of Net Price Change Due to a Net Increase in Total Crop Output

ΔP_{ijt} = $(P_{j,t-1} \cdot \Delta P_{ijt})/(Q_{j,t-1} \cdot E_j)$, where

ΔP_{ijt} = the net change in the price of crop j attributable to the application of pesticide i (i.e., Fenox) in year t,

$P_{j,t-1}$ = the price of crop j in year (t-1),

ΔQ_{ijt} = the net change in the total output of crop j in the nation attributable to application of pesticide i (i.e., Fenox) in year t,

$Q_{j,t-1}$ = the total output of crop j in year (t-1),

E_j = the price elasticity of demand for crop j.

1. Wheat

t = 1973

$P_{j,t-1}$ = \$1.76 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 22,473,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 1,544,936,000 bushels (*Agricultural Statistics, 1974*, Table 2),

E_j = - 0.75,

ΔP_{ijt} = - \$0.03414 per bushel.

t = 1978

$P_{j,t-1}$ = \$2.961 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 26,601,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 1,616,926,600 bushels (A. Smith, *et al.*, *op. cit.*, p. 31),

E_j = - 0.75,

ΔP_{ijt} = - \$0.06495 per bushel.

EXHIBIT 3.11 (continued)

2. Barley

$t = 1973$ $P_{j,t-1}$ = \$1.22 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 10,215,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 423,461,000 bushels (*Agricultural Statistics, 1974*, Table 59),

E_j = - 0.75,

ΔP_{ijt} = - \$0.03924 per bushel.

$t = 1978$ $P_{j,t-1}$ = \$1.712 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 12,095,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 484,246,790 bushels (A. Smith, *et al.*, *op. cit.*, p. 31),

E_j = - 0.75,

ΔP_{ijt} = - \$0.05701 per bushel.

3. Oats

$t = 1973$ $P_{j,t-1}$ = \$0.723 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 31,988,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 691,973,000 bushels (*Agricultural Statistics, 1974*, Table 50),

E_j = - 0.75,

ΔP_{ijt} = - \$0.04456 per bushel.

EXHIBIT 3.11 (continued)

t = 1978 $P_{j,t-1}$ = \$0.921 per bushel (Exhibit 3.12),

ΔQ_{ijt} = 38,195,000 bushels (Exhibit 3.10),

$Q_{j,t-1}$ = 854,074,920 bushels (A. Smith, *et al.*, *op. cit.*, p. 31),

E_j = - 0.75,

ΔP_{ijt} = - \$0.05492 per bushel.

EXHIBIT 3.12: Prices Paid to Farmers for Crops
(Data in dollars per bushel)

Crop	Year				
	Average 1970-1972*	1972**	1973**	1977***	1980****
Wheat	1.487	1.760	3.820	2.961	1.815
Barley	1.044	1.220	2.040	1.712	1.274
Oats	0.651	0.723	1.090	0.921	0.794

*Averaged from Agricultural Statistics, 1974, 1971.
**Agricultural Statistics, 1974, Tables 2, 50, and 59.
***Interpolated from 1973 and 1980 data.
****A. Smith, *et al.*, *op. cit.*, 1974, Table 19, p. 45. (Assumes a 4 percent inflation and a 1 percent supply shift from the price level in 1970-1972.)

3.1.4 Change in Consumers' Surplus

The result of the net price changes from Exhibit 3.11, when applied to the total net increase in yield in bushels from Exhibit 3.10, gives the total value to society of the net increase in yield -- i.e., change in consumers' surplus -- as shown in Exhibit 3.13. The values for 1974 through 1977 have been interpolated and all values have been discounted back to their value in 1974. Also shown is the five year total for 1974 through 1978, discounted to its value in 1974.

3.2 Net Costs of Pesticide Application

In the determination of the net costs of pesticide application, the assumption is made that the total costs of pesticide application with Fenox are five percent higher than they are with Delta. This hypothetical assumption does not appear to be unreasonable considering the hypothetical yield increases assumed for Fenox.

To determine the actual value of this increased cost, the cost of applying Delta is first determined. The total cost of applying a herbicide to a crop consists of two elements -- the cost of the herbicide materials and the cost of performing the application. Using standard spray application costs from Doane's Agricultural Report, the costs of application per acre for Delta are shown in Exhibit 3.14, and the total cost of application for Delta, to the acres which would be treated with Fenox rather than Delta, are shown in Exhibit 3.15.

The five year (1974-1978) total cost discounted back to 1974 is expected to be 105.4 million dollars if Delta were used. This implies that the cost with Fenox can be expected to be (1.05) x (105.4) = 110.7 million dollars, for a net increase in application cost of 5.3 million dollars, if Fenox were substituted for its next best alternative Delta.

This change in costs of pesticide application should normally be embodied within the change in the consumers' surplus measure when one pesticide is substituted for another. This should occur because the change in the crop price resulting from a change in crop yield and a change in pesticide application cost should be reflected in the price forecasting algorithm. Thus, the purpose of separately determining the net costs of pesticide application is usually to determine the distributional impacts to the farmer associated with this substitution.

EXHIBIT 3.13: Calculation of Net Internal Benefits to Society When Fenox is Substituted for Its Next Best Alternative Delta*

Year	Current Dollars (In millions of dollars)				Discounted Value in 1974 (In millions of dollars)*			
	Crop				Crop			
	Wheat	Barley	Oats	Total	Wheat	Barley	Oats	Total
1973	53.1	16.8	31.5	101.4	53.1	16.8	31.5	101.4
1974	63.6	19.0	34.8	117.4	63.6	19.0	34.8	117.4
1975	74.0	21.2	38.1	133.3	64.7	18.5	33.0	116.2
1976	84.5	23.5	41.4	149.4	64.6	18.0	31.6	114.2
1977	94.9	25.7	44.7	165.3	63.4	17.2	29.9	110.5
1978	105.4	28.0	48.0	181.4	61.5	16.3	28.0	105.8
1974-1978	422.4	117.4	207.0	746.8	317.8	89.0	157.3	564.1

*The following equation was used in this calculation: $\Delta CS_{jt} = \Delta P_{jt} \cdot Q_{j,t-1} + 1/2 \cdot \Delta P_{jt} \cdot \Delta Q_{jt}$. Explanation of the terms appear on p. 3.1.

**The discounted value is calculated by dividing the current dollars by $(1 + r)^t$, where r is the discount rate and t is the number of years discounted. The recommended discount rate to be used is 10 percent when benefits and costs are expressed in constant dollars (see Volume I of report, pp. 3.21-3.22). Therefore, in this instance, where a 4 percent inflation has been built into the analysis, the appropriate discount rate is (1.04) x (1.1) - (1) = 0.144, or 14.4 percent.

EXHIBIT 3.14: Cost of Herbicide Treatments Per Acre for Delta

R_{it} = cost per pound of materials
AC_{ijkt} = cost per acre of performing application } Assume values are same for all crops

		North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific	United States Average
1972	Materials* ($/pound)	1.82	1.72	1.75	1.67	1.74	1.53	1.72	1.79	1.85	1.92	1.75
	Application** ($/acre)	2.43	1.35	1.89	1.51	1.94	1.45	1.45	1.48	1.75	1.75	1.70
1973 ***	Materials ($/pound)	1.90	1.79	1.83	1.74	1.81	1.60	1.79	1.87	1.93	2.00	1.82
	Application ($/acre)	2.43	1.35	1.89	1.51	1.94	1.45	1.45	1.48	1.75	1.75	1.70
1978 ***	Materials ($/pound)	2.28	2.11	2.22	2.09	2.18	1.92	2.11	2.24	2.32	2.41	2.19
	Application ($/acre)	2.44	1.36	1.90	1.52	1.95	1.46	1.46	1.49	1.76	1.76	1.71
1980 ****	Materials ($/pound)	2.43	2.30	2.34	2.23	2.33	2.05	2.30	2.39	2.47	2.57	2.34
	Application ($/acre)	2.45	1.36	1.91	1.52	1.96	1.46	1.46	1.49	1.77	1.77	1.72

*Agricultural Prices, Annual Summary, 1972, p. 162.

**Doane's Agricultural Report, March 17, 1972.

***Interpolated from 1980 data.

****Forecast from A. Smith, et al., op. cit., Table 19, p. 45.

EXHIBIT 3.15: Total Cost of Herbicide Treatments with Delta
Assume two treatments per acre (pre- and post-emergence)* (Data are in hundreds of dollars)

		North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific	United States Total
1973	Wheat 0.90**	5,388	15,002	49.765	25,086	7,107	5,165	12,767	8,961	8,589	7,844	145,674
	Barley 0.46**	861	1,973	1,156	7,947	2,969	436	---	1,605	5,836	5,084	27,867
	Oats 0.20**	2,935	2,936	32,587	8,926	1,994	1,643	8,439	3,667	661	742	64,530
	Total	9,184	19,911	83,508	41,959	12,070	7,244	21,206	14,233	15,086	13,670	238,071
1978	Wheat 0.90**	6,724	19,030	63,082	31,839	8,969	6,554	16,095	11,341	10,879	9,956	184,469
	Barley 0.46**	1,067	2,473	1,398	9,883	3,620	632	---	2,005	7,202	6,295	34,483
	Oats 0.20**	4,322	3,551	39,597	10,858	2,428	2,016	10,260	4,422	797	921	79,172
	Total	12,113	25,054	104,077	52,580	15,025	9,102	26,355	17,768	18,878	17,172	298,124
Five-year total (1974-1978)***												1,370,508
Five-year total (1974-1978) discounted back to 1974****												1,053,770

*TC_{ijt} = $TPC_{ijt} + TAC_{ijt}$, where:
TPC_{ijt} = total material cost = $R_{it} \cdot \sum_k$(application rate for one treatment $\cdot\ 2 \cdot TCPA_{ijkt}$), and
TAC_{ijt} = total application cost = $\sum_k (AC_{ijkt} \cdot 2 \cdot TCPA_{ijkt})$

**Application rates for two treatments per acre (given in lbs/acre).

***The years 1974 through 1977 were interpolated and then the years 1974 through 1978 were added together.

****Each of the five years 1974 through 1978 was discounted back to its value in 1974 and then added together. The procedure is fully explained in Exhibit 3.13.

In the present case study, the price forecasting algorithm has only included the change in crop price due to an increase in crop yield. Therefore, the net increase in application cost of 5.3 million dollars is not included in the consumers' surplus measure and must be considered in the determination of net benefits.

A second distributional impact of interest (and related to pesticide application costs) is the change in the farmers' profit from substituting Fenox for Delta. Shoud Fenox be substituted for Delta, there will be an increase in total crop output accompanied by a decrease in crop price. This will result in a decrease in total revenue to the farmer as indicated in Exhibit 3.16. This measure, however, gives no indication as to what the change in the farmers' profit may be. Assuming the farmer can reduce his total cost of crop production* by sufficiently more than the decrese in his revenue, he will increase his profit by using Fenox rather than Delta.

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*Pesticide application costs are only one small part of the total cost of crop production. Costs for other inputs would be needed to determine the change in total cost of crop production, and then the change in the farmers' profit.

EXHIBIT 3.16: Change in Revenue to Farmers if Fenox is Registered and Substituted for Delta

Calculated from Exhibit 3.11 as $[(P_{j,t-1} + \Delta P_{ijt}) \times (Q_{j,t-1} + \Delta Q_{ijt})] - [(P_{j,t-1}) \times (Q_{j,t-1})]$

(In millions of dollars)

	Wheat	Barley	Oats	Total
1973	-14.0	-4.5	-2.6	-21.1
1978	-28.0	-7.6	-13.8	-49.4
5 year total (1974-1978)*	-112.0	-31.6	-46.4	-190.0
5 year total (1974-1978) discounted back to 1974**	-84.1	-23.9	-33.8	-141.8

*The years 1974 through 1977 were interpolated and then the years 1974 through 1978 were added together.

**Each of the five years 1974 through 1978 was discounted back to its value in 1974 and then added together. The procedure is fully explained in Exhibit 3.13.

4.0 HEALTH EFFECTS

4.1 Description of Study Pesticide and Its Next Best Alternative

In the health effects discussion, Fenox and its next best alternative, Delta, are defined as fabricated chlorophenoxy herbicides. The characteristics of Delta are assumed to be given by any data of record on 2,4-D; 2,4,5-T; Silvex; MCPA or Sesone (2,4-dichlorophenoxyethyl sulfate). Based upon hypothetical animal toxicology data, Fenox is hypothetically assumed to be similar to Delta in terms of its chronic injury hazards. However, its ocular exposure hazard and dermal exposure hazard are hypothetically assumed to be more severe as indicated later in the analysis. Both Fenox and Delta are assumed to be formulated as 10 percent water solutions and in such purity that no chlorophenoxy dioxins can be detected in the product sold. Furthermore, the health effects associated with the use of Fenox are limited to those effects caused by its use in wheat, oats, and barley production.

4.2 Subpopulations at Risk

It is assumed that the proposed registration of Fenox is intended for agricultural use by people involved in the production of wheat, oats, and barley. Hence, in Exhibit 5.2 of the health effects submodel in Volume I of the report, the entities referred to as "professional nonfarm applicators" and "household users of pesticides" need not be considered, as Fenox's proposed uses would not give rise to an occasion where these subgroups would be at risk or impacted by this product. In addition, the entity "pesticide transport personnel" is assumed to be at minimal risk (based on past discussions with OPP personnel) and is not considered in the assessment of health effects.

Therefore, the subpopulations at risk and considered in the following discussion of health effects are as follows:

- Pesticide R and D, manufacturing, and formulation workers,
- Field workers and other farm personnel,

- Commercial farm applicators, and
- Society as a whole.

Each of these subgroups is further described, below.

4.2.1 Pesticide R and D, Manufacturing and Formulation Workers

In order that Fenox will be available in sufficient quantity to meet the demand for its use, a number of manufacturing and formulation employees will be needed to produce Fenox. From discussions with a typical formulator of phenoxy herbicide products,* it is estimated that approximately 18 manufacturing and formulating employees are needed to produce and formulate one million pounds of the typical phenoxy herbicide per year. This includes all functions -- production, formulation, maintenance, supervision, and laboratory. Therefore, assuming that the demand for Fenox in 1974 for wheat, oats, and barley production will be as described in the agricultural impact analysis,** the number of manufacturing and formulating employees at risk in 1974 would have been 61. For 1975 through 1978, these numbers would be 63, 67, 68, and 70, respectively, based on the demand projections for use of Fenox on wheat, oats, and barley crops.

4.2.2 Field Workers and Other Farm Personnel

Health effects to this subgroup would only impact on those members of the subgroup directly involved with the use of Fenox on wheat, oats, and barley, whether it be in the application of Fenox on these crops or the entering of wheat, oats or barley fields sprayed with Fenox.

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*The cooperation of Amchem Products, Incorporated, Ambler, Pennsylvania 19002, is greatly appreciated.

**Based on acres treated with Fenox and application rate data presented in the agricultural impact analysis, 3.3 million pounds of Fenox would have been needed in 1973 and 3.9 million pounds would be needed in 1978. Interpolating this data for 1974-1977 implies that 3.4 million pounds, 3.5 million pounds, 3.7 million pounds, and 3.8 million pounds, respectively, will be needed.

To determine the portion of this subgroup at risk from use of Fenox in this manner, information from the agricultural impact analysis was used. More specifically, only those states that had wheat, oats or barley crops were assumed to have field workers who would be at risk. To estimate the number of agricultural workers in any state working on wheat, oats or barley crops, the following formula was used:

$$N_i = AW_i \times \frac{CGW_i}{TW_i} \times \frac{WOBA_i}{CGA_i}$$

where: N_i = the number of agricultural workers in state i working on wheat, oats or barley crops,

AW_i = the total number of agricultural workers in state i,

CGW_i = the number of hired farm workers in state i working less than 150 days a year on cash grain crops,

TW_i = the total number of hired farm workers in state i working less than 150 days,

$WOBA_i$ = the number of wheat, oats, and barley acres harvested in state i,

CGA_i = the number of cash grain acres harvested in state i.

N_i then had to be adjusted to reflect the number of workers in the state that are expected to be exposed to the pesticide. This was accomplished by assuming that an equal number of agricultural workers work each acre of wheat, oats or barley. Thus, the number of agricultural workers in any state working on wheat, oats or barley crops and that would be exposed to Fenox was estimated as follows:

$$NE_i = N_i \times \frac{WOBAF_i}{WOBA_i}$$

where: NE_i = the number of agricultural workers in state i working on wheat, oats or barley crops expected to be exposed to Fenox,

N_i = defined as before,

$WOBAF_i$ = the number of wheat, oats, and barley acres in state i receiving Fenox,

$WOBA_i$ = defined as before.

Results of these calculations appear in Exhibit 4.1. The number of agricultural workers in 1973, expected to have worked on wheat, oats or barley crops in the United States that would be treated with Fenox if registered, is 35,610. It is assumed that this number will remain stable over the five year period 1974-1978.*

4.2.3 Commercial Farm Applicators

Commercial application of Fenox on wheat, oats, and barley predominantly involves aerial application of the product. Presently, there are approximately 4,300 aerial farm applicator firms in the United States, with 7,800 planes and 25,000 employees. However, of these 25,000 employees, only 17,550 are directly involved in the aerial spraying of pesticides. Furthermore, it is estimated that only one-third of this number, or 5,850, are engaged in phenoxy herbicide spraying.**

Although 5,850 aerial farm applicators are engaged in phenoxy herbicide spraying, not all will be at risk if Fenox is registered for use on wheat, oats, and barley crops. In 1971, approximately 39.4 percent of all phenoxy herbicides used by farmers were used on wheat, oats, barley, and other grain crops.*** Therefore, assuming that this

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*This assumption is supported by the fact that the number of agricultural workers in each state has remained fairly constant over the past couple of years (USDA, Agricultural Statistics, 1974, p. 434). Thus, if the proportions, CGW_i/TW_i, $WOBA_i/CGA_i$, and $WOBAF_i/WOBA_i$, remain fairly stable, the assumption is not unreasonable.

**Based on a phone conversation with Mr. Farrell Higbee, National Agricultural Aviation Association, Washington, D.C., April 3, 1975.

***Andrilenas, P. A., Farmers Use of Pesticides in 1971: Quantities, USDA, ERS, Agricultural Economic Report No. 252, July, 1974, pp. 30, 32.

EXHIBIT 4.1: Derivation of the Number of Agricultural Workers Expected to be Exposed to Fenox When Applied on Wheat, Oats, and Barley Crops (All Numbers are in Thousands)

	AW_i[1]	CGW_i[2]	TW_i[3]	$WOBA_i$[4]	CGA_i[5]	$WOBAF_i$[6]	N_i	NE_i
Northeast Region								
Maine	18	0.276	41.832	34	34	3.14	4.10	0.38
New York	99	1.606	100.095	477	853	44.17	0.89	0.08
New Jersey	19	0.580	30.590	61	144	5.64	0.15	0.01
Pennsylvania	116	2.076	83.381	794	1,849	73.52	1.20	0.11
Delaware	6	1.235	12.549	48	243	4.44	0.12	0.01
Maryland	32	3.079	32.663	238	750	22.03	0.96	0.09
Total	290	9.329	301.110	1,652	3,873	153.00	7.40	0.69
Lake States Region								
Michigan	121	13.496	176.547	921	2,670	59.03	3.19	0.20
Wisconsin	173	2.725	120.433	1,418	3,517	90.89	1.58	0.10
Minnesota	183	29.489	139.015	5,454	11,064	349.60	19.14	1.23
Total	477	45.710	435.995	7,793	17,251	500.00	23.90	1.53
Corn Belt Region								
Ohio	155	24.014	131.168	1,272	4,320	353.90	8.35	2.33
Indiana	143	29.333	105.988	975	6,253	271.30	6.17	1.72
Illinois	162	75.895	165.000	1,704	11,470	474.22	11.07	3.08
Iowa	201	51.891	208.742	1,352	12,506	376.26	5.41	1.51
Missouri	187	23.422	128.506	904	3,963	251.58	7.77	2.16
Total	848	204.555	739.404	6,207	38,512	1,728.00	38.78	10.70
Northern Plains								
North Dakota	58	32.201	57.894	13,503	13,790	426.42	31.59	1.00
South Dakota	65	7.983	50.575	5,039	8,165	159.13	6.33	0.20
Nebraska	110	27.201	83.971	3,173	11,172	100.20	10.12	0.32
Kansas	111	38.352	101.346	10,580	16,060	334.11	27.67	0.87
Total	344	105.737	293.786	32,295	49,187	1,020.00	75.71	2.39
Southern Plains								
Oklahoma	120	14.539	86.874	4,140	6,534	145.70	17.49	0.45
Texas	264	36.144	253.188	5,689	12,314	200.25	12.67	0.62
Total	384	50.683	340.062	9,829	18,848	345.00	30.16	1.06
Appalachian Region								
Virginia	103	3.172	95.698	319	898	70.97	1.21	0.27
West Virginia	36	.057	15.603	40	103	8.90	0.05	0.01
Kentucky	148	7.158	189.456	231	1,260	51.39	1.03	0.23
Tennessee	147	9.014	113.410	187	730	41.60	2.99	0.67
North Carolina	197	12.355	439.272	297	1,793	66.08	0.92	0.20
Total	631	31.756	853.438	1,074	4,784	239.00	6.20	1.38

EXHIBIT 4.1 (continued)

	AW_i[1]	CGW_i[2]	TW_i[3]	$WOBA_i$[4]	CGA_i[5]	$WOBAF_i$[6]	N_i	NE_i
Southeast Region								
South Carolina	64	7.549	107.473	193	672	64.32	1.29	0.43
Georgia	100	5.266	133.247	204	2,023	67.99	0.40	0.13
Alabama	83	3.774	72.793	108	749	35.99	0.62	0.21
Florida	115	2.124	120.941	41	381	13.66	0.22	0.07
Total	362	15.316	434.454	546	3,825	182.00	2.50	0.84
Delta States								
Mississippi	109	10.872	80.427	102	360	102.00	4.17	4.17
Arkansas	126	28.748	90.900	284	987	284.00	11.47	11.47
Louisiana	68	13.487	60.689	26	737	26.00	0.53	0.53
Total	303	53.107	232.016	412	2,084	412.00	16.17	16.17
Mountain								
Montana	39	10.661	38.809	6,322	6,333	158.42	10.69	0.45
Wyoming	15	0.720	15.751	422	456	10.57	0.63	0.02
Idaho	44	7.152	83.703	1,955	1,983	48.99	3.71	0.09
Colorado	57	8.374	59.281	2,736	3,470	68.56	6.35	0.16
New Mexico	22	1.738	22.066	312	696	7.81	0.78	0.02
Utah	21	1.149	32.755	403	416	10.09	0.71	0.02
Nevada	47	0.108	4.885	31	31	0.78	3.22	0.08
Arizona	32	1.121	52.646	336	485	0.84	0.47	0.01
Total	277	31.023	281.748	12,517	1,387	314.00	26.56	0.84
Pacific								
Washington	75	10.193	218.245	3,145	3,221	143.75	3.40	0.16
Oregon	58	4.112	225.409	1,402	1,420	64.08	1.04	0.05
California	280	16.583	671.703	1,622	2,545	74.14	4.41	0.20
Total	413	30.888	1,115.357	6,169	7,186	282.00	8.88	0.41
U.S. -Total	4,329	578.104	5,027.371	78,494	146,937	5,175.00	236.29	35.61

Sources:

1. USDA, Agricultural Statistics, 1974, Washington, D.C., Superintendent of Documents, 1974, Table 618. Data is for 1973.
2. U. S. Bureau of the Census, Census of Agriculture, 1964, Vol. 2: General Reports, Chapter 4, Equipment, Labor, Expenditures, Chemicals, Table 11, p. 77. Data is for 1969.
3. Ibid.
4. Agricultural Statistics, 1974, Calculated from Tables 2, 20, and 59. Data is for 1973.
5. Agricultural Statistics, 1974, Calculated from Tables 2, 20, 27, 39, 50, 59, and 71. Data is for 1973.
6. Derived from regional totals in agricultural impact analysis; see Chapter 3.0 of this volume. Data is for 1973. (State data may not add to regional total due to rounding.)

percentage has not drastically changed over the years and that farmer use of phenoxy herbicides on wheat, oats, and barley is directly related to aerial farm application of phenoxy herbicides on wheat, oats, and barley, then it may be estimated that 2,305 aerial farm applicators (39.4 percent of 5,830) would be spraying Fenox on wheat, oats, and barley crops and thus be at risk. It is assumed that this number would remain fairly constant over a short time span of five years.

4.2.4 Society As A Whole

Society is at risk in an indirect manner if Fenox is used on wheat, oats, and barley. More specifically, acute injury can occur to society when there is drift of the product in the vicinity of its application as a result of accidental spills or misuse. To estimate the portion of society at such a risk, the following equation can be used:

$$N_t = \sum_{i=1}^{n} R_{it} \times \frac{WOBAF_{it}}{RA_{it}}$$

where: N_t = the number of people in society at risk to acute injury from use of Fenox on the wheat, oats, and barley crops at time t,

n = the states in which wheat, oats, and barley are grown,

R_{it} = the size of the rural population in state i at time t,

$WOBAF_{it}$ = the number of wheat, oats, and barley acres in state i receiving Fenox in year t,

RA_{it} = the total number of rural acres in state i in year t, in rural land area expressed in acres.

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*Acute injury to society from the R and D, manufacture, formulation, and distribution of Fenox for use on wheat, oats, and barley is assumed to be zero. This is based on information about 2,4-D and 2,4,5-T contained in E. W. Lawless, et al., The Pollution Potential in Pesticide Manufacturing, EPA, Office of Water Programs, Technical Studies Report TS-00-72-04, June, 1972.

Two data elements -- R_{it} and RA_{it} -- are not readily available from the Bureau of the Census but can be obtained through extensive data manipulation of its readily available data. Therefore, this formula is recommended for use. However, for illustrative purposes only, the equation below has been used to estimate that portion of society at risk to acute injury from the proposed use of Fenox on the wheat, oats, and barley crops:*

$$N_t = \sum_{i=1}^{n} P_{it} \times \frac{WOBAF_{it}}{A_{it}}$$

where: N_t = defined as before,

P_{it} = the size of the total population in state i at time t,

n = defined as before,

$WOBAF_{it}$ = defined as before,

A_{it} = the total number of acres in state i in year t, i.e., total land area expressed in acres.

Exhibit 4.2 presents the results of the above calculations. As shown in the exhibit, the number of people in the United States at risk to acute injury from Fenox's use on wheat, oats, and barley is estimated to be 762,000 in 1974. For 1975 through 1978, the numbers of people are 798,000; 834,000; 872,000; and 909,000, respectively.

The risk of chronic injury to society would only result from dietary intake of the pesticide. Consequently, the entire United States population is at such a risk and was estimated at 211,390,000 people as of July 1, 1974.** For 1975 through 1978, these estimates are

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*This equation assumes an equal distribution of people throughout a state. Because this is not a reasonable assumption, this equation is far less desirable than the previous one.

**Bureau of the Census, Population Estimates and Projections, Series P-25, No. 539, January, 1975.

EXHIBIT 4.2: Derivation of the Society at Risk to Acute Injury from Use of Fenox on Wheat, Oats, and Barley Crops (All numbers are in thousands)

Region*	P_{it}[1]					$WOBAF_{it}$[2]					A_{it}[3]	N_t				
	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978		1974	1975	1976	1977	1978
Northeast	44,194	44,605	45,016	45,433	45,850	161.6	170.2	178.8	187.4	196.0	91,591	77.97	82.52	87.78	92.68	97.66
Lakes States	17,921	18,139	18,349	18,563	18,777	321.4	536.8	552.2	573.6	592.0	121,964	76.61	79.79	82.57	87.25	90.13
Corn Belt	35,696	36,028	36,360	36,693	37,025	1,792.4	1,856.8	1,921.2	1,985.6	2,050.0	164,964	387.85	405.31	423.23	441.48	459.85
Northern Plains	5,012	5,037	5,062	5,087	5,112	1,057.6	1,095.2	1,132.8	1,170.4	1,208.0	144,238	36.75	38.25	39.76	41.28	42.81
Southern Plains	14,490	14,671	14,852	15,037	15,222	357.2	369.4	381.6	393.8	406.0	211,786	24.44	25.59	26.75	27.95	29.18
Appalachia	19,138	19,273	19,408	19,549	19,690	247.8	256.6	263.4	274.2	283.0	123,920	38.27	39.90	41.55	43.20	44.85
Southeast	18,289	18,535	18,781	19,027	19,274	188.8	195.6	202.4	209.2	216.0	125,746	27.46	28.82	30.22	31.64	33.08
Delta States	7,970	8,020	8,070	8,120	8,171	561.8	581.6	601.4	621.2	641.0	92,269	48.53	50.55	52.60	54.66	57.76
Mountain	8,824	8,956	9,088	9,220	9,352	325.4	336.8	348.2	359.6	371.0	547,869	5.24	5.51	5.78	6.05	6.33
Pacific	27,462	28,016	28,574	29,133	29,691	292.4	302.8	313.2	323.6	334.0	204,233	39.32	41.52	43.80	46.15	48.54
United States Total	198,996	201,276	203,578	205,881	208,184	5,506.4	5,701.8	5,900.2	6,098.6	6,297.0	1,879,583	762.44	797.76	834.04	872.28	909.19

*The states in each region are as defined in Exhibit 4.1.

Sources:
1. Bureau of the Census, Population Estimates and Projections, Series P-25, No. 477, March, 1972, Series I-E Projections.
2. Interpolated from data in Exhibit 3.8 of agricultural impact analysis.
3. Calculated from Bureau of the Census, County and City Data Book, 1972, Table 1.

214,883,000; 217,293,000; 219,703,000; and 222,113,000, respectively.*

4.3 Net Health Damages

4.3.1 Determination of Net Health Damages Using Animal Toxicology Data

4.3.1.1 Acute Injury Assessment

Below appears an assessment of the increased acute injury, based upon animal toxicology data, which is caused by exposure to Fenox rather than Delta. These calculations follow the definitions developed in Section 5.2.1.2 of Volume I of this report. For ease of understanding the analysis below, these definitions are repeated at this time.**

For acute injury, each hazard defined below contemplates injuries sufficiently severe to cause:

- The victim to purchase and apply an ameliorative preparation, or
- The victim to seek medical advice or treatment, or
- The victim to lose time from work.

In addition, each hazard can be expressed as the number of individuals affected among each 100,000 exposed to the pesticide product in the subpopulation indicated by the left-hand headings of Exhibit 5.2 of Volume I of the report. Furthermore, due to the uncertainty of extrapolating from animal toxicology data to likely human health effects, a range for each hazard that incorporates the probable value of each hazard is desirable. Therefore:

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*Bureau of the Census, Population Estimates and Projections, Series P-25, No. 477, March, 1972, Series I-E projections.

**See p. 5.4 of Volume I of the report for the basis for these prodefinitions.

- Ocular exposure hazard is defined as eight to twelve times the number of rabbit eyes among six tested which suffered irreversible opacity at two days, plus four to six times the number which suffered corneal opacity reversible within two days or irritation persisting for seven days, plus 0.5 to 1.5 times the number which suffered irritation reversible within seven days, when ocularly exposed with 0.1 ml of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest.

- Dermal exposure hazard is defined as eight to twelve times the number of rabbits among six tested which suffered necrosis or marked erythema evident at 72 hours, plus four to six times the number which suffered moderate erythema evident at 72 hours, plus 0.5 to 1.5 times the number which suffered any visible lesser degree of irritation evident at 72 hours, when dermally exposed -- i.e., when applied to both covered and uncovered skin, both intact and abraded -- with 0.01 ml of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To the sum of these three degrees of primary irritation should be added eight to twelve times the number of guinea pigs sensitized to any degree among a group of 10 tested to account for the dermal sensitizing potential of the pesticide product.

- Oral exposure hazard is defined as 100 divided by the rat oral LD$_{50}$ (expressed in ml/kg body weight) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range for this hazard, one can use the mean LD$_{50}$ and the 95 percent confidence interval LD$_{50}$'s.

- Inhalation exposure hazard is defined as 4,000* divided by the 4-hour rat LC_{50} (expressed as milligrams per liter of air) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range of this hazard, one can use the mean LC_{50} and the 95 percent confidence interval LC_{50}'s.

- Systemic poisoning hazard is defined as the sum of oral exposure hazard, percutaneous exposure hazard** and inhalation exposure hazard for the subpopulation of interest.***

- Death hazard is defined as one-twentieth of the systemic poisoning hazard for the subpopulation of interest.****

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*This number was derived so that the resulting oral exposure hazard and inhalation exposure hazard would be equivalent for an oral LD_{50} and an inhalation LC_{50} that are equally toxic according to the "Toxicity Categories" tabulation in the October 16, 1974, Federal Register.

**Percutaneous exposure hazard is defined as 100 divided by the rabbit percutaneous LD_{50} (expressed in ml/kg body weight) of the pesticide product, in the solvent and at the concentration expected to be handled by the subpopulation of interest. To obtain a range for this hazard, one can use the mean LD_{50} and the 95 percent confidence interval LD_{50}'s. In addition, percutaneous exposure is assumed to produce systemic poisoning.

***Systemic poisoning can occur via the oral, dermal penetration or inhalation routes of entry. This definition assumes that for each person experiencing irritation by oral or inhalation exposure, there will be an additional person more severely exposed such that systemic poisoning will result. Therefore, these two exposure hazards are added to percutaneous exposure hazard.

****Death can occur via the oral, dermal penetration or inhalation routes of entry just as systemic poisoning. This definition assumes that for every 20 persons experiencing systemic poisoning, there will be an additional person more severely exposed such that death will result.

Emphasis must be made that these definitions will only provide very rough estimates of what the expected exposure hazard may be. They are crude estimating techniques and thus the results generated by them must be interpreted with considerable care and reservation.

4.3.1.1.1 Ocular Exposure Hazard

Data required to apply this definition are not published in the scientific literature, but should be available in every petition for registration to allow drafting of warning and precautionary statements. An example of original laboratory records (marked "Page 9") of such a test on an 8 percent water solution, instead of a 10 percent water solution, of the sodium salt of 2,4-D, applying 0.5 ml, instead of 0.1 ml as in the definition, is on the following page. Four of five eyes suffered irritation reversible within seven days, and this can be interpreted as five of six. Therefore, applying the definition above, this example generates an ocular exposure hazard of (1 ± 0.5) x (5) = 5 ± 2.5 per 100,000 exposed to an 8 percent water solution of Delta.

Hypothetically assuming that a similar test with Fenox would produce a result of one out of six eyes suffering corneal opacity reversible within two days, plus four out of six eyes suffering irritation reversible within seven days, an ocular exposure hazard of (5 ± 1) x (1) + (1 ± 0.5) x (4) = 9 ± 3 per 100,000 exposed to an 8 percent water solution of Fenox, would be generated.

The above hypothetical result implies a net increase in the ocular exposure hazard of (9 ± 3) - (5 ± 2.5) = 4 ± 0.5 per 100,000 exposed to an 8 percent water solution, if Fenox is substituted for its next best alternative Delta.

Manufacturing and formulation workers are assumed to be exposed to undiluted Fenox or Delta. Further assuming a linear dose-response curve for Fenox and Delta,* the net increase in ocular exposure hazard to this subgroup is expected to be (12.5) x (4 ± 0.5) = 50 ± 6.25 per 100,000 exposed.

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*Most dose-response curves are S-shaped and not linear. However, in the mid-range of the curve, a linear dose-response relationship may hold quite well. Therefore, this assumption may be a reasonable one. Further investigation of this relationship for these pesticides would be needed in order to verify the validity and sensitivity of the assumption made.

Material	Sample	Solvent (V= vapor)	% or ppm.	Ml. or min.	Animal No.	Eye	Immediate Result	Twenty-four Hour Result					Rating	Healing on page	Dates 19____	
							p. o	Lids i. c. e. h. p. n	Sclera i. e. n	Iris is	Cornea d. o. e. k. p	F. Stain %. pp. l. d. r			Check. Due	Read
Z-41) (na. salt)	11730	H2O	8%	.5	462	L	p	p,c				15-%ld	3		10/5-	10/6
					463	L	φ	p,c		is		15%ld	4			
					453	R	p	c				O.K.	0			
					458	R	φ	p,c		is		25%ld	4			
					459	R	φ	c				15-%ld	2			
	11-165	PG	1%	~~.5~~	467	L	o	pSw c		is	d	95%ld	9		10/6	10/7
	11-165	PG	1%	.5	472		φ	pSw c		is	d	100%ld	9			
	"	"	"	"	473		P	PSw cn		is	d	100%ld	9			
	"	"	"	"	474		P	PSw		is	d	100%ld	9			
	"	"	"	[illegible]	482			PSw		is	d	100%ld	9			
	11-178	PG	1%	.5	484							3%lp	1			
	11-178	"	"	"	488							5%l	1			
	11-180	H2O	1%	.5	491							O.K.	0			
	11-198	PG	1%	.5	494							O.K.	0			
	11-180	H2O	1%	.5	496	L						~~[illegible]~~ O.K.	0			
	11-178	PG	1%	.5	471	R						2%lp	1			
	11-180	H2O	1%	.5	481							3%pp	1			

4.14

Abbreviations (Use Capitals for marked symptom):-

Immediate
p=pain
o=opacity

Lids and Sclera
i=injected capillaries
c=congested
e=edema
h=hemorrhage
p=pus or exudate
n=necrosis

Iris
is=internal congestion

Cornea
d=dull
o=opaque
e=edema
k=keratoconus
p=perforation

F. Stain
%=portion stained
pp=pinpoint spots
l=light or diffuse
d=dense
r=reticular

Form 20b [illegible] 12-43

Recorded by 227<

Farm workers and commercial farm applicators are assumed to be at risk during the mixing and dilution of the pesticide, during the application of the pesticide, and during the disposal of the pesticide. No data could be found indicating the relative frequency of accidents caused by each process. Therefore, the assumption is made that most accidents will occur during the application process, after the pesticide is diluted.* Assuming farm workers would dilute the 8 percent water solution by approximately 100 before using,** and assuming a linear dose-response curve, the net increase in ocular exposure hazard to each of these two subgroups is expected to be $(4 \pm 0.5) \div (100) = 0.04 \pm 0.005$ per 100,000 exposed.

Society as a whole would be exposed to Fenox or Delta if drift occurred during the manufacturing or application process. However, should this occur, it is assumed that Fenox or Delta would be in such a dilute form as to pose virtually no net change in ocular exposure hazard.

4.3.1.1.2 Dermal Exposure Hazard

Data required to apply the definition are not published in the scientific literature. Those for primary irritation should be available in every petition for registration to allow drafting of warning and precautionary statements. An example of original laboratory records (marked "Page 45") of such a test on a 10 percent acetone solution of 2,4-D is on the following page. Spot 3 shows (at 24, not 72 hours) one rabbit suffered marked erythema, one moderate erythema, and two lesser degrees of irritation. This result would generate a primary irritation hazard of $(10 \pm 2) \times (1) + (5 \pm 1) \times (1) + (1 \pm 0.5) \times (2) = 17 \pm 4$ per 100,000 exposed to a 10 percent water solution of Delta. No example

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*Further analyses of these two subpopulation groups are needed before an accurate assessment can be made concerning where the likely exposure will be. If this information were desired, and if it were obtained, the technique used above should be modified to incorporate this new information.

**From discussions with people knowledgeable in the use of agricultural pesticides (e.g., Dr. Herbert Cole, Pennsylvania State University), this assumption appears to be a reasonable one. Dilution of the bought product usually occurs and a factor of 100 is one standard form of dilution.

Reproduced from best available copy.

RABBIT BELLY TEST

[✓ #17, Vesicant]
#18, 4 Hour
#19, 24 Hour

CORDED BY

YEAR

aterial	Sample	Dilution and Solvent	Ml.	Animal No.	Spot	Reaction - Hours			Date	To Sum.
						0. 4	24	48		
H2SO4	—				1		I		6/24	
yl Mercurate	11-43				2		I			
2-4-D	11-130	10% in [illegible]			3		i			
[illegible]	11-134	Undil			4		E,O			
Ceresan	11-106	10% in H2O			5		E			
12.59	9-193	10% in [illegible]			6		—			
					1		—			
					2		i			
					3		I			
					4		I			
					5		e			
					6		E			
					1		E			
					2		—			
					3		e			
					4		E			
					5		I			
					6		E,e			
					1		E			
					2		i			
					3		—			
					4		i			
					5		i			
					6		i			
					1		i			
					2		E,O			
					3		E			
					4		—			
					5		e			
			total	Mean	6		E			
	—	2,1,3,1,3	11	2.2						
	11-43	2,2,4,1,4	13	2.6						
	11-130	1,2,2,1,1	7	1.4						
	11-134	5,3,5,4,6	23	4.6						
	11-106	4,4,4,1,4	17	3.4						
	4-193	-,-,-,-,-	0.0	0.0						

CTION

i = minor injection
I = major injection
e = minor erythema
E = major erythema
o = minor edema
O = major edema
n = minor necrosis
N = major necrosis

Score only worst symptom on each spot.

No. 17 Total Score=mean of five animals.

No. 18 Total Score=total of five animals.

If any spot scores over 4 record total as 20+ and give number of animals with o,O,n,N separately.

No. 19 Total score=total of five animals.

Hyd. Form 20

of a publication of data on sensitizing potential of a chlorophenoxy herbicide product has been found. Experience leads to the conclusion that sensitization is more likely from the solvent than from the herbicide,* and it is assumed that Delta products use non-sensitizing solvents.

Hypothetically assuming a similar test with Fenox would produce a result of two rabbits suffering marked erythema, one moderate erythema and one lesser degree of irritation, a dermal exposure hazard of (10 ± 2) x (2) + (5 ± 1) x (1) + (1 ± 0.5) x (1) = 26 ± 5.5 per 100,000 exposed to a 10 percent water solution of Fenox, is generated. As with Delta, Fenox is assumed to use non-sensitizing solvents, so that no sensitization is expected.

The above hypothetical results imply a net increase in dermal exposure hazard of (26 ± 5.5) - (17 ± 4) = 9 ± 1.5 per 100,000 exposed to a 10 percent water solution, if Fenox is substituted for its next best alternative Delta.

Manufacturing and formulation workers are assumed to be exposed to undiluted Fenox or Delta. Further assuming a linear dose-response curve, the net increase in dermal exposure hazard to this subgroup is expected to be (10) x (9 ± 1.5) = 90 ± 15 per 100,000 exposed.

Farm workers and commercial farm applicators are assumed to be at risk during the application process. Assuming that they will dilute the 10 percent water solution by 100 before using and assuming a linear dose-response curve, the net increase in dermal exposure hazard to each of these two subgroups is expected to be (9 ± 1.5) ÷ (100) = 0.09 ± 0.015 per 100,000 exposed.

Society as a whole would be exposed to Fenox or Delta if drift occurred during the manufacturing or application process. However, should this occur, it is assumed that Fenox or Delta would be in such a dilute form as to pose virtually no net change in dermal exposure hazard.

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*Opinion of Dr. Henry F. Smyth, Jr., toxicologist and Advisory Fellow, Mellon Institute.

4.3.1.1.3 Oral Exposure Hazard

Carpenter, et al.,* reported that the rat oral LD_{50} of the chlorophenoxy herbicide "Sesone," when intubated as a 10 percent solution in water, is approximately 0.84 ± 0.20 ml/kg. This shows that the rat oral LD_{50} for the Delta product consisting of 10 percent Delta, 0.01 percent nonionic wetting agent, in water is assumed to be approximately 0.84 ± 0.20 ml/kg, leading to an estimate of oral exposure hazard of (100) ÷ (0.84 ± 0.20) or a range of 96.15 to 156.25 per 100,000 exposed to a 10 percent water solution of Delta.

Hypothetically assuming a similar test with Fenox would produce the same results, the oral exposure hazard with Fenox would be the same as with Delta. Hence, the net change in oral exposure hazard to a 10 percent water solution is expected to be zero per 100,000 exposed, if Fenox is substituted for its next best alternative Delta.

Therefore, it is expected that there will be no net change in oral exposure hazard to any of the subpopulations exposed.

4.3.1.1.4 Inhalation Exposure Hazard

No data on the acute inhalation toxicity of a phenoxy herbicide could be found. However, the ACGIH threshold limit value (TLV) committee has reviewed reports of repeated oral feeding studies and concluded that a TLV of 10 mg/m^3 of air is appropriate for 2,4-D.* This is the value assigned to inert dusts such as wood and limestone and can be taken as the best available opinion that there is no inhalation exposure hazard so long as the time weighted average concentration of Delta during eight hours does not exceed 10 mg/m^3 of air.

Hypothetically assuming that Fenox is similar to Delta in this respect, the same statement can be made.

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*Carpenter, C. P., et al., "Mammalian Toxicity of Sesone Herbicide," Agricultural and Food Chemistry, Vol. 9, No. 5, September/October, 1961.

**American Conference of Governmental Industrial Hygienists, Documentation of Threshold Limit Values for Substance in Workroom Air, third edition, 1971, p. 67.

One can conclude from these results that the 4-hour LC_{50} for rats is a concentration too great to be maintained in air. Since Fenox and Delta are to be formulated as a 10 percent solution in water and applied by diluting by 100, one may take the inhalation exposure hazard for both Fenox and Delta as zero per 100,000 exposed for all subpopulations.

Thus, the net change in the inhalation exposure hazard is also expected to be zero per 100,000 exposed for all subpopulations, if Fenox is substituted for its next best alternative Delta.

4.3.1.1.5 Percutaneous Exposure Hazard

The 1974 Toxic Substances List published by NIOSH reports the rat percutaneous LD_{50} of 2,4-D -- a Delta parallel -- to be 1,500 mg/kg. More useful than that datum is the 1974 report of Feldman and Maibach on experimental percutaneous penetration in humans.* They found that an acetone solution applied to the uncovered skin at the rate of four micrograms of 2,4-D per square centimeter, allowed to dry, and not washed for 24 hours, resulted in 5.8 percent of the dose in the urine. From this it is assumed that the human percutaneous hazard is approximately one-sixteenth the oral exposure hazard, or a range of 6.0 to 9.8 per 100,000 exposed to a 10 percent water solution of Fenox.

Hypothetically assuming a similar test with Fenox would produce the same results, the percutaneous exposure hazard with Fenox would be the same as with Delta. Hence, the net change in percutaneous exposure hazard is expected to be zero per 100,000 exposed to a 10 percent solution, if Fenox is substituted for its next best alternative Delta.

Therefore, it is expected that there will be no net change in percutaneous exposure hazard to any of the subpopulations exposed.

4.3.1.1.6 Systemic Poisoning Hazard

Systemic poisoning hazard is defined as the sum of the oral, percutaneous, and inhalation exposure hazards. Therefore, if exposed to a 10 percent water solution of either Fenox or Delta, the systemic

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*Feldman, R. J., and H. I. Maibach, "Percutaneous Penetration of Some Pesticides and Herbicides in Man," *Toxicology and Applied Pharmacology*, Vol. 28, 1974, pp. 126-132.

poisoning hazard is expected to be between (96.15 + 6.0 + 0) = 102.15 and (156.25 + 9.8 + 0) = 166.05 per 100,000 exposed. Thus, the net change in systemic poisoning hazard is expected to be zero per 100,000 exposed to a 10 percent water solution, if Fenox is substituted for its next best alternative Delta.

Therefore, it is expected that there will be no net change in systemic poisoning hazard to any of the subpopulations exposed.

4.3.1.1.7 Death Hazard

Death hazard is defined as one-twentieth of the systemic poisoning hazard. Therefore, if exposed to a 10 percent water solution of either Fenox or Delta, the systemic poisoning hazard is expected to be between (102.15) ÷ (20) = 5.1 and (166.05) ÷ (20) = 8.3 per 100,000 exposed. Thus, the net change in death hazard is expected to be zero per 100,000 exposed to a 10 percent water solution, if Fenox is substituted for its next best alternative Delta.

Therefore, it is expected that there will be no net change in death hazard to any of the subpopulations exposed.

4.3.1.2 Chronic Injury Assessment

Based on animal toxicology data, the assessment of the chronic injury hazards caused by exposure to Delta (and also Fenox, as the two are assumed to have the same chronic injury hazards),* could not be performed using the probabilistic approach of probit analysis outlined in Volume I of the report (pp. 5.12-5.13). The available data for constructing the necessary dose-response regression lines for each desired effect either were questionable or non-existent. Therefore, meaningful data could not even be fabricated, as there was no basis for such an exercise. In addition, accurate estimates for the expected average daily intake could not be found for all routes of entry and all subpopulation groups. These data, although not readily available at the present time, have been recommended to be included in the data requirements of the registration process. If this is done, then the procedure can be used with some success.

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*See page 4.1.

The procedure that is used below relies on published animal toxicology data to determine a so-called "no effect" level in a selected test species for a selected phenoxy herbicide for the various chronic effects in question. These "no effect" levels are then reduced by a factor of safety of 10, explained below, and evaluated in terms of whether the subpopulation groups could be expected to be exposed to such a level.

This procedure has been used in past studies and is relied upon when determining non-hazardous levels in humans for new substances to which the human race has not been exposed to extensively. Tolerances for pesticide residues in raw agricultural commodities are also set using this kind of information.* Although not as rigorous or desirable as the probabilistic method described in Volume I, it is felt that this procedure does provide as good an indication of the chronic injury hazard as would be obtained using the more rigorous method with less reliable data.

4.3.1.2.1 Metabolism and Elimination

Gehring, et al.,** and Piper, et al.,*** taken together, show that neither the rat nor man metabolize or conjugate small dosages (5 mg/kg) of 2,4,5-T -- a Delta parallel -- although larger dosages are somewhat metabolized by the rat and were not tested in man. In these species, oral doses are recoverable from the urine. Contrasted with this, in the dog, at least three unidentified metabolites occur in the urine, and an appreciable part of a dose is eliminated in the feces.

Accordingly, the rat is an appropriate experimental species for prediction of human systemic response to intake of Delta. However, there is some difference in the time of elimination of a dose between man and rat, the half-life of 5 mg/kg of Delta in the human body being 23.1 hours and in the rat body 13.6 hours. Had there been no difference

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*See Federal Register, March 11, 1975, p. 1493.

**Gehring, P. J., et al., "The Fate of 2,4,5-T Following Oral Administration to Man," Toxicology and Applied Pharmacology, Vol. 26, 1973, pp. 352-361.

***Piper, W. N., et al., "The Fate of 2,4,5-T Following Oral Administration to Rats and Dogs," Toxicology and Applied Pharmacology, Vol. 26, 1973, pp. 339-351.

in time of elimination, one would have been justified in ignoring the customary arbitrary factor of safety of 100.* Despite the fact that the test dosage of 5 mg/kg is tremendous compared to the WHO established acceptable daily intake (ADI) of 0.3 mg/kg for residues in food grains,** and is large compared to any likely occupational exposure, it would be prudent to consider that even realistic dosages will remain somewhat longer in the human body than in that of the rat. Hence, a factor of safety of 10, rather than 100, seems appropriate in this instance when assessing chronic injuries caused by Delta.

Hypothetically assuming that Fenox is like Delta in this respect, a factor of safety of 10 is also appropriate when assessing chronic injuries caused by Fenox.

4.3.1.2.2 Mutagenic Hazard

Epstein, et al.,*** found no mutagenic result in rats receiving a single intraperitoneal injection of 125 mg/kg or five daily stomach tube doses of 75 mg/kg of 2,4-D -- a Delta parallel. Applying the previously determined proposed safety factor of 10 to these findings, it is concluded that no mutagenic hazard is expected to occur at a human intake of 7.5 mg/kg or less.

As shown in a later section,**** the human dietary intake by society as a whole from use of Delta on wheat, oats, and barley can be expected to be close to zero. Thus, there is no expectation of mutagenic hazard to society as Delta is not expected to be consumed by society at the rate necessary to cause harm, when it is used in wheat, oats or barley production.

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*First proposed by A. J. Lehman of the Food and Drug Administration for dealing with new substances to which the human race has not yet been exposed extensively. See Federal Register, March 11, 1975, p. 1493.

**WHO, Pesticide Residue in Food, WHO Technical Report Series No. 525, Geneva, WHO/FAO, 1973, p. 29.

***Epstein, S. S., et al., "Detection of Chemical Mutagens by the Dominant Lethal Assay in the Mouse," Toxicology and Applied Pharmacology, Vol. 23, 1972, pp. 288-325.

****See Section 4.3.2.4, "Acute and Chronic Injury to Society."

For the occupationally exposed, although their dietary intake is expected to also be close to zero, additional human intake can result from direct oral, dermal, and inhalation exposures to Delta when produced for or used in wheat, oats, and barley production. However, if the occupational exposure from these three routes of entry, plus any dietary intake, does not produce an intake of more than 7.5 mg/kg, mutagenic hazards in the occupationally exposed can be expected to be zero. There is no evidence in the literature to date that indicates occupational exposure has or would exceed this amount, unless someone were trying to commit suicide. Therefore, one can assume the intake of Delta by the occupationally exposed does not exceed 7.5 mg/kg, and based on animal toxicology data, one can expect that there is no mutagenic hazard to those occupationally exposed to Delta.

Considering that Fenox has been defined to be similar to Delta with respect to chronic injury hazards, one can also expect that there is no mutagenic hazrd to society or to those occupationally exposed to Fenox.

Therefore, for all subpopulations, it follows that the net change in mutagenic hazard is zero per 100,000 exposed, if Fenox is substituted for its next best alternative Delta.

4.3.1.2.3 Teratogenic Hazard

Khera and McKinley* studied the teratogenic potential of pure** 2,4,5-T -- a Delta parallel -- on rats. At 100 mg/kg, teratogenic pups were found. At 50 mg/kg, there was no significant difference from the controls. Applying the previously determined proposed factor of safety of 10 to this finding, it is concluded that no teratogenic hazard is expected to occur at a human intake of 5 mg/kg or less.

As shown in a later section, the human dietary intake by society as a whole from use of Delta on wheat, oats, and barley can be expected to be close to zero. Thus, there is no expectation of teratogenic hazard to society as Delta is not expected to be consumed by society at the rate necessary to cause harm, when it is used in wheat, oats or barley production.

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*Khera, K. S., and W. P. McKinley, "Pre- and Post-Natal Studies on 2,4,5-T and 2,4-D and Their Derivatives in Rats," Toxicology and Applied Pharmacology, Vol. 22, 1972, pp. 14-28.

**One mg/kg of dioxin was present.

For the occupationally exposed, although their dietary intake is expected to also be close to zero, additional human intake can result from direct oral, dermal, and inhalation exposures to Delta when produced for or used in wheat, oats, and barley production. However, if the occupational exposure from these three routes of entry, plus any dietary intake, does not produce an intake of more than 5 mg/kg in pregnant women, teratogenic hazards in the occupationally exposed can be expected to be zero. There is no evidence in the literature to date that indicates occupational exposure has or would exceed this amount, unless someone were trying to commit suicide. Therefore, one can assume the intake of Delta by the occupationally exposed does not exceed 5 mg/kg, and based on animal toxicology data, one can expect that there is no teratogenic hazard to those occupationally exposed to Delta.

Considering that Fenox has been defined to be similar to Delta with respect to chronic injury hazards, one can also expect that there is no teratogenic hazard to society or to those occupationally exposed to Fenox.

Therefore, for all subpopulations, it follows that the net change in teratogenic hazard is zero per 100,000 exposed, if Fenox is substituted for its next best alternative Delta.

4.3.1.2.4 Oncogenic Hazard, Reproductive Impairment, and Physiological Malfunction Hazard

Hansen, et al.,* reported on a three generation, six litter reproduction study and on a two-year feeding to rats of diets containing up to 1,500 ppm of 2,4-D -- a Delta parallel. No incidence of tumors or physiological malfunction could be found from 500 ppm in the diet, but at 1,500 ppm, there was a reduction in the number of pups which survived to weaning and in the weights of weanlings. Five hundred ppm in the diet of adult rats is 25 mg/kg/day.** Applying the previously

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*Hansen, W. H., et al., "Chronic Toxicity of 2,4-Dichlorophenoxyacetic Acide in Rats and Dogs," Toxicology and Applied Pharmacology, Vol. 20, 1971, pp. 122-129.

**An adult rat weighs 400 grams and eats 20 grams of dry food/day. Therefore, 1 ppm in the diet of an adult rat is 0.02 mg or 0.05 mg/kg body weight/day. Thus, 500 ppm is 25 mg/kg/day.

determined proposed factor of safety of 10 to this finding, it is concluded that at a human intake of 2.5 mg/kg/day or less, no oncogenic hazard, reproductive impairment or physiological malfunction hazard is expected.

As shown in a later section, the human dietary intake by society as a whole from use of Delta on wheat, oats, and barley can be expected to be close to zero. Thus, there is no expectation of oncogenic hazard, reproductive impairment or physiologic malfunction hazard to society as Delta is not expected to be consumed by society at the rate necessary to cause harm, when it is used in wheat, oats or barley production.

For the occupationally exposed, although their dietary intake is expected to also be close to zero, additional human intake can result from direct oral, dermal, and inhalation exposures to Delta when produced for or used in wheat, oats, and barley production. However, if the occupational exposure from these three routes of entry, plus any dietary intake, does not produce a daily intake of more than 2.5 mg/kg, oncogenic hazard, reproductive impairment and physiological malfunction hazards can all be expected to be zero. There is no evidence in the literature to date that indicates occupational exposure has or would exceed this amount unless someone were trying to commit suicide. Furthermore, even if an occupationally exposed person inhaled, for eight hours, air containing 10 mg/m^3* of Delta, this would only represent a daily intake of 1.14 mg/kg,** well below the 2.5 mg/kg level. Therefore, one can assume the intake of Delta by the occupationally exposed does not exceed 2.5 mg/kg, and based on animal toxicology data, one can expect that there is no danger of these types of hazards occurring to those occupationally exposed to Delta.

Considering that Fenox has been defined to be similar to Delta with respect to chronic injury hazards, one can also expect that there is no oncogenic hazard, reproductive impairment or physiological malfunction hazard to society or to those occupationally exposed to Fenox.

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*This is the TLV for Delta (see page 4.18).

**A man breathes approximately 1 cubic meter of air per hour when at work or 8 cubic meters of air per work day. Assuming the air contains 10 mg/m^3 of Fenox, he would inhale 80 mg of Fenox a day. For a 70 kg man, this represents 1.14 mg/kg/day.

Therefore, for all subpopulations, it follows that the net change in oncogenic hazard, reproductive impairment or physicological malfunction hazard is zero per 100,000 exposed, if Fenox is substituted for its next best alternative Delta.

4.3.2 Determination of Net Health Damages Using Human Experience Data

In this section of the health effects analysis, the effects caused by Delta are assumed to be given by any human data of record on exposure to any of the phenoxy herbicides. Furthermore, the human data that would be generated if people were exposed to Fenox are assumed to be the same, except in cases where the animal toxicology data have been hypothesized to be otherwise.

4.3.2.1 Acute and Chronic Injury to R and D, Manufacturing and Formulation Workers

Acute and chronic injury to R and D, manufacturing and formulation workers producing Fenox for use in wheat, oats, and barley production will result from oral, dermal, ocular and/or inhalation exposures.* To estimate the extent of these injuries, a recent study of 73 male workers in a 2,4,5-T plant was used.** The average age of the employees was 39.3 years and the average duration of employment was 8.3 years. However, duration of employment was not a very significant factor in the severity of many conditions; rather, individual susceptibility was more important.*** In this study, the following health effects, including their frequencies in parentheses, were noted among the employees as being caused by exposure to 2,4,5-T:

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*Chronic injury is not expected to result from dietary intake of Delta because the dietary intake of Delta is expected to be sufficiently close to zero as discussed under Section 4.3.2.4, "Acute and Chronic Injury to Society."

**Poland, A. P., et al., "A Health Survey of Workers in a 2,4-D and 2,4,5-T Plant," Archives of Environmental Health, Vol. 22, March, 1971, pp. 316-327.

***Ibid., pp. 316, 324.

- Ocular
  - Conjunctival injection+ (4.1%)
  - Itching of eyes++ (9.6%)
  - Blootshot eyes++ (6.9%)
  - Frequent tearing++ (19.2%)
  - Stics++ (9.6%)
- Dermal*
  - Severe chloracne+ (17.8%)
  - Hyperpigmentation+ (41.1%)
  - Hirsutism+ (21.9%)
  - Scarring+ (35.6%)
  - Uroporphyrinuria+ (1.4%)
  - Porphyria+ (0.0%)
- Oral
  - Inflammation of buccal mucosa+ (10.9%)
- Inhalation
  - Hyperemia of nasal mucosa+ (31.5%)
- Systemic poisoning**
  - Nausea, vomiting, diarrhea, abdominal pains, blood in stool+ (30.0%)
  - Leg fatigue+ (2.7%)
  - Diminished proprioception+ (1.4%)
  - Decreased auditory acuity+ (8.2%)
- Death
  - No mention of deaths in the plant from exposure to 2, 4, 5-T was made. It is assumed to be zero.
- Mutagenesis, teratogenesis, oncogenesis and reproductive impairment were not studied.

+Based on physical examination.

++These were complaints made by employees.

*Major cause was dioxins in 2, 4, 5-T; ibid., p. 316.

**The validity of these findings are conjectural and it is uncertain if the pesticide is the only cause for the frequencies being what they are.

• Physiologic malfunction	
.. Abnormal function of cardiovascular, pulmonary, intermediary metabolic, or hematologic systems+	(0.0%)
.. Liver disfunction+	(0.0%)
.. Lack of vigor, lessened drive, libido, emotional instability, diminished ability to learn+	(17.8%)*

If one assumes that the R and D, manufacturing and formulation workers exposed to Delta will be exposed in a similar fashion as those exposed in the above mentioned 2, 4, 5-T plant and that the workers in the above mentioned plant are no more or less susceptible to health injury than the employees of the Delta plant, then the above incidences can be used to estimate the expected incidences for R and D, manufacturing and formulation workers exposed to Delta. Thus, the following incidences have been generated to estimate these various types of injury:

• Acute injury	
.. Ocular exposure hazard	96/1000 exposed**
.. Dermal exposure hazard	103/1000 exposed***
.. Oral exposure hazard	109/1000 exposed
.. Inhalation exposure hazard	315/1000 exposed
.. Systemic poisoning	300/1000 exposed****
.. Death	None

+Based on physical examination.

*Percentage based on fact that a significant correlation found between severe chloracne and high score on the manic scale of the Minnesota Multiphasic Personality Inventory (MMPI).

**This rate was based on the most prevalent ocular effect excluding "frequent tearing" because it was felt "frequent tearing" would only occur while at work and would not result in lost work, the seeking of medical advice or the taking of medication.

***Dioxins have been shown to be the major cause of chloracne problems and all dermal effects have been shown to correlate significantly with chloracne. Because Delta is assumed to have no detectable dioxins, dermal exposure hazard was arbitrarily estimated as one-fourth the most prevalent dermal effect.

****This rate was based on the most prevalent systemic poisoning effect.

- Chronic injury
  - Physiologic malfunction hazard 45/1000 exposed*

As indicated in the beginning of this chapter and in the animal toxicology section (i.e., Section 4.3.1), only ocular and dermal exposure hazards were assumed to be more severe for Fenox than for Delta. More specifically, the hypothetical animal toxicology data generated an ocular exposure hazard for Fenox of approximately two times the ocular exposure hazard for Delta** and a dermal exposure hazard for Fenox of approximately 1.5 times the dermal exposure hazard of Delta.*** This implies that the ocular and dermal exposure hazards for Fenox can be expected to be 192 and 155, respectively, per 1,000 manufacturing and formulation workers exposed, based on human experience data. Therefore, the net increase in ocular and dermal exposure hazards can be expected to be 96 and 52, respectively, per 1,000 manufacturing and formulation workers exposed, if Fenox is substituted for its next best alternative Delta. All other acute and chronic hazards are assumed to be the same for both Fenox and Delta for a net change of zero per 1,000 exposed.

4.3.2.2 Acute and Chronic Injury to Field Workers and Other Farm Personnel

Although phenoxy herbicides have been extensively used in agriculture, very little information is available that will allow one to calculate the incidence rates for various types of injuries among farm workers. Perhaps the best information available is from the State of California. The California Department of Public Health, Bureau of Occupational Health and Environmental Epidemiology, has published for a number of years a report titled Occupational Disease in California Attributed to Pesticides and Other Agricultural Chemicals. The most recent and complete report seen has been for 1970. However, additional data for 1971 and 1972 has also been obtained.

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*This rate was based on the chloracne rate because psychological effects correlated significantly with chloracne. However, one-fourth the chloracne rate was used following similar reasoning as in footnote *** on the previous page.

**See Section 4.3.1.1.1.

***See Section 4.3.1.1.2.

In the California report, pesticides are not listed individually, but rather by types, one of which is herbicides. Therefore, in estimating the health effects of Delta on farm workers, the assumption is made that Delta will produce the same kinds of effects on farm workers that herbicides, in general, produced.

Proceeding with this background information, the 1970 Report states that there were 711* reports of occupational disease among farm laborers caused by pesticides and other agricultural chemicals. This translates into an incidence of 3.7/1000** farm workers. However, only 14 percent*** (100 out of 711) of these reports involved herbicides, implying that the incidence for occupational disease among farm laborers caused by herbicides is 0.52/1000 farm workers.

This incidence must then be adjusted to obtain the incidence per 1,000 farm workers exposed to herbicides, as the present incidence is based on all farm workers in the state and not just those exposed to herbicides. This is important because not all cropland are treated with herbicides and thus not all farm workers are exposed to herbicides.

In 1970, one study estimated that only 2.33 percent of California's cropland received 2,4-D and that the average application rate was 0.88 lb/acre.**** Assuming an equal number of farm workers per acre of California cropland, only 2.33 percent of the farm workers were exposed to herbicides in 1970. This implies that the incidence of occupational disease per 1,000 farm workers exposed to herbicides is 0.52/0.0233, or 22.3 percent.*****

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*California Department of Public Health, Bureau of Occupational Health and Environmental Epidemiology, Occupational Disease in California Attributed to Pesticides and Other Agricultural Chemicals, 1970, p. 25.

**Ibid., p. 10.

***Ibid., p. 25.

****Crockett, A. B., et al., "Pesticide Residue Levels in Soils and Crops, FY 70, National Soils Monitoring Program (II)," Pesticides Monitoring Journal, Vol. 8, No. 2, September, 1974, p. 79.

*****It must be stated that this incidence is a crude estimate and it understates the actual incidence of occupational disease because it is based on reports of occupational disease only. Thus, numerous cases of occupational disease caused by herbicide exposure are not accounted for because they never are reported. Yet, this is the best information available. In the case of a real benefit-cost analysis of a pesticide, greater care should be taken to get a better estimate if possible.

Returning to the California study, data shows that of all occupational disease in 1970 involving herbicides, 14 percent produced systemic poisoning, 5 percent involved a respiratory condition, 39 percent involved a skin condition, and 43 percent involved an eye condition.* For 1971, these percentages were 11, 4, 35, and 49, respectively, and for 1972, they were 10, 4, 36, and 50, respectively. No agricultural worker deaths were reported in 1970.

Applying an average of the above percentages of each occupational disease involving herbicides to the incidence of occupational disease per 1,000 farm workers exposed to herbicides, gives the following incidences of acute injury for farm workers exposed to herbicides when applied at a rate of approximately 0.88 lb/acre:

•	Ocular exposure hazard	10.5/1000 exposed
•	Dermal exposure hazard	8.2/1000 exposed
•	Oral exposure hazard	Included in systemic poisoning
•	Inhalation exposure hazard	1.0/1000 exposed
•	Systemic poisoning	2.6/1000 exposed
•	Death	None

Assuming that Delta is applied on wheat, oats, and barley in a similar manner and at a similar rate as herbicides were applied in California, these incidences can be used as estimates of the acute injury likely to be incurred by farm workers when exposed to use of Delta on wheat, oats or barley crops. Considering the fact that Delta is assumed to be applied at a rate of 0.2-0.9 lb/acre and these incidences were caused by a 0.88 lb/acre application rate, this assumption is a reasonable one.

Following the same arguments made above in Section 4.3.2.1, the ocular and dermal exposure hazards to farm workers exposed to Fenox can be expected to be 21 and 12.3, respectively, per 1,000 exposed, based on human experience data. This implies a net increase in ocular and dermal exposure hazards of 10.5 and 4.1, respectively, per 1,000 farm workers exposed, if Fenox is substituted for its next best alternative Delta. All other acute hazards are assumed to be the same for both Fenox and Delta for a net change of zero per 1,000 exposed.

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*California Department of Public Health, op. cit., p. 24.

With respect to chronic injury among farm workers caused by exposure to phenoxy herbicides, no information has been found based on human experience data. Therefore, the assessment of chronic injury among farm workers caused by exposure to either Delta or Fenox must be based solely on results of animal toxicology data.

4.3.2.3 Acute and Chronic Injury to Commercial Farm Applicators

When looking for information concerning acute and chronic injury to commercial farm applicators from application of phenoxy herbicides, one faces the same problems as with the agricultural worker subpopulation. Once again, the only information available appears to be from the State of California, in the same report cited previously.

In the 1970 California report, there were 227* reports of occupational disease among agricultural service workers caused by pesticides and other agricultural chemicals. This translates into an incidence of 9.2/1000** agricultural service workers. Most of these reports were received from spraying and pest control service firms and therefore this incidence does reflect the likelihood of illness among spraying and pest control workers*** when exposed to pesticides or other agricultural chemicals. Of these 227 reports, only 11 percent**** (24 out of 227) involved herbicides, implying that the incidence for occupational disease among agricultural service workers caused by herbicides is 1.0/1000 agricultural service workers. This number also represents the incidence per 1,000 agricultural service workers exposed to herbicides as all agricultural service workers are exposed to some kind of

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*California Department of Public Health, op. cit., p. 25.

**Ibid., p. 10.

***The incidence actually understates the rate of occupational disease among this group for two reasons. First, the incidence is based on all agricultural service employees when most of the illness occurred in only one segment of all agricultural service employees, i.e., spraying and pest control workers. Second, the incidence is based on reported cases and not actual illnesses. Many go unreported as with the agricultural worker subpopulation, but this information is still the best available.

****California Department of Public Health, op. cit., p. 25.

pesticides by the very nature of their business. Thus, the incidence does not have to be adjusted for only those agricultural service workers exposed to herbicides.

Applying the average percentage of each type of occupational disease involving herbicides obtained in the previous section to the incidence of occupational disease per 1,000 agricultural service workers exposed to herbicides, gives the following incidences of acute injury for agricultural service workers exposed to herbicides when applied at a rate of approximately 0.88 lb/acre:

. Ocular exposure hazard	0.47/1000 exposed
. Dermal exposure hazard	0.37/1000 exposed
. Oral exposure hazard	Included in systemic poisoning
. Inhalation exposure hazard	0.04/1000 exposed
. Systemic poisoning	0.12/1000 exposed
. Death	None*

Assuming that Delta is applied on wheat, oats, and barley in a similar manner and at a similar rate as herbicides were applied in California, these incidences can be used as estimates of the acute injury likely to be incurred by agricultural service workers when exposed to use of Delta on wheat, oats or barley crops. Considering the fact that Delta is assumed to be applied at a rate of 0.2-0.9 lb/acre and these incidences were caused by a 0.88 lb/acre application rate, this assumption is a reasonable one.

Following the same arguments made above in Section 4.3.2.1, the ocular and dermal exposure hazards to commercial farm applicators exposed to Fenox can be expected to be 0.94 and 0.55, respectively, per 1,000 exposed, based on human experience data. This implies a net increase in ocular and dermal exposure hazards of 0.47 and 0.18, respectively, per 1,000 commercial farm applicators exposed, if Fenox is substituted for its next best alternative Delta. All other acute hazards are assumed to be the same for both Fenox and Delta for a net change of zero per 1,000 exposed.

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*No deaths were reported in 1970 for agricultural service workers from exposure to pesticides.

With respect to chronic injury to commercial farm applicators caused by exposure to phenoxy herbicides, no information has been found based on human experience data. Therefore, the assessment of chronic injury among commercial farm applicators caused by exposure to either Delta or Fenox must be based solely on results of animal toxicology data.

4.3.2.4 Acute and Chronic Injury to Society

Acute injury to society from use of Delta on wheat, oats, and barley crops would result from drift of the product during and subsequent to the application process. However, in reviewing the published scientific literature, there have been no reports of acute injury to society caused by drift of 2,4-D and 2,4,5-T from treated fields. The lack of such reports and the presence of similar reports for other pesticides, such as organophosphates,* leads one to conclude that accidents of this nature have not been found to occur with phenoxy herbicides. Therefore, one may also assume that these types of accidents will not occur with the use of Delta on wheat, oats, and barley. Hence, there is no reason to believe that acute health injury will accrue to society when Delta is used on wheat, oats, and barley crops.

Similar arguments are assumed for Fenox; therefore, the result is expected to be the same as for Delta. This implies that a net change of zero in the incidence of acute injury to society is expected, if Fenox is substituted for its next best alternative Delta.

Chronic health injury will accrue to society through their dietary intake of pesticides in the food they eat, in the air they breathe or in the water they drink. However, the majority of this intake will occur in the food.** Considering that Delta is being analyzed with respect to its use on wheat, oats, and barley crops, dietary intake of Delta can only result from residues left on grains and cereals produced for human consumption and grains and cereals produced for animal feed that are then in turn fed to animals slaughtered for human consumption. Pesticide residues in total diet samples have been analyzed for the past seven

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*See Report of the Secretary's Commission on Pesticides and Their Relationships to Environmental Health, U.S. DHEW, 1969.

**Ibid., p. 384.

years under the Total Diet Program supervised by the Food and Drug Administration. In the most recent report,* no phenoxy herbicide was found in ready-to-eat dairy products, cereals and grains, and meat, fish and poultry during the period, June 1970-April 1971. In addition, older reports also showed that no phenoxy herbicide was commonly found in these same ready-to-eat products.**

The approximate limit of quantification for analysis of chlorophenoxy acid herbicides is 0.02 ppm.*** Therefore, there is the possibility that phenoxy herbicides may be present in these ready-to-eat products, but at levels where detection is impossible. Even if this were the case, the levels would still be far below the WHO established acceptable daily intake (ADI) of 0.3 mg/kg for 2,4-D residues in food grains,**** because a 70 kg man would have to ingest (0.3 mg/kg) x (70 kg) = 21 mg of the phenoxy herbicide per day or 1,050 kg of food grains per day containing 0.02 mg/kg of the phenoxy herbicide. This occurrence can be assumed to be zero, which implies any phenoxy herbicide intake from its use on wheat, oats, and barley will be well below the ADI of 0.3 mg/kg and more likely close to zero.

Therefore, assuming that Delta will be applied to wheat, oats, and barley crops at similar rates as its related phenoxy herbicides, there is no indication that Delta will be ingested at any amount (through the food products generated either directly or indirectly from the production of wheat, oats or barley treated with Delta), sufficient enough to cause any chronic injury. Hence, it is expected that there will be no chronic injury to society as a result of Delta being used on wheat, oats, and barley crops.

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*Manske, D. D., and P. E. Corneliussen, "Pesticide Residue in Total Diet Samples (VII)," Pesticides Monitoring Journal, Vol. 5, No. 2, September, 1974.

**The older reports referred to are the second, third, and fourth total diet sample studies. They appeared in the Pesticides Monitoring Journal, Vol. 1, No. 2, September, 1967; Vol. 1, No. 4, March, 1968; and Vol. 2, No. 4, March, 1969 issues, respectively, and covered the periods, June 1965-April 1966, June 1966-April 1967, and June 1967-April 1968, respectively.

***Manske, D. D., and P. E. Corneliussen, op. cit., p. 111.

****WHO, op. cit., p. 29.

Similar arguments are assumed for Fenox; therefore, the result is expected to be the same as for Delta. This implies that a net change of zero in the incidence of chronic injury to society is expected, if Fenox is substituted for its next best alternative Delta.

4.3.3 Summary of Net Health Damages

In the previous two sections -- 4.3.1 and 4.3.2 -- the change in incidences of acute and chronic injury from exposure to Fenox when substituted for Delta, and when used on wheat, oats, and barley crops, were calculated for various subpopulation groups. This was accomplished by using two methods -- one relied on animal toxicology data and the second relied on human experience data.

In some instances, the net incidences determined by the two methods for the same injury/subpopulation group combination varied a great deal. In this summary section, each injury/subpopulation cell of Exhibit 5.2 of Volume I of the report was completed using the higher of the two net incidences, so that the assessment of the net health damages from the substitution of Delta with Fenox on wheat, oats, and barley crops would be a liberal estimate rather than a conservative estimate.

Therefore, Exhibit 4.3 summarizes the net health damages by presenting the expected net incidences for the various types of acute and chronic injuries to be incurred by the various subpopulation groups. One will note that the net health damages expected to result from the substitution of Delta with Fenox on wheat, oats, and barley crops are acute in nature and will impact on those occupationally exposed, with the highest increased incidence occurring in the formulating and manufacturing subpopulation and the lowest increased incidence occurring in the commercial farm applicator subpopulation.

These increased incidence rates can then be coupled with the number of people in each subpopulation group expected to be exposed in each of the five years from 1974 through 1978 when Fenox is substituted for Delta and used in wheat, oats, and barley production. That is, assuming these increased incidence rates will remain fairly constant over a 5-year period, Exhibit 4.4 presents the number of additional people in each subpopulation group expected to incur the various types of health damages in each of the five years, based on the assumptions made about the size of each subpopulation group exposed during this period. In terms of absolute numbers, field workers and other farm personnel are expected to incur the most additional health damage and commercial farm applicators the least.

EXHIBIT 4.3: Net Incidence of Health Damages from Substitution of Delta with Fenox on Wheat, Oats, and Barley Crops (Given as number per 1,000 exposed)

Entity Incurring Health Damage	Type of Health Damage										
	Acute Injury						Chronic Injury				
	Morbidity										
	Ocular Exposure Hazard	Dermal Exposure Hazard	Oral Exposure Hazard	Inhalation Exposure Hazard	Systemic Poisoning	Mortality (Death)	Mutagenic Hazard	Terato-genic Hazard	Oncogenic* Hazard	Reproductive Impairment	Physiologic Malfunction Hazard*
Occupational Health Damage to:											
Pesticide R&D Manufacturing and Formulation Workers	96	52	0	0	0	0	0	0	0	0	0
Pesticide Transport Personnel	Not determined but assumed to be negligible based on discussions with OPP personnel										
Field Workers and Other Farm Personnel	10.5	4.1	0	0	0	0	0	0	0	0	0
Commercial Farm Applicators	0.47	0.18	0	0	0	0	0	0	0	0	0
Professional Non-Farm Applicators (PCO's, government employees, etc.)	na	na	na	na	na	na	na	na	na	na	na
General Public Health Damage to: Household Users of Pesticides (through direct exposure)	na	na	na	na	na	na	na	na	na	na	na
Society as a Whole (through indirect exposure)	0	0	0	0	0	0	0	0	0	0	0

na = not applicable

*In particular, with respect to central nervous system, hematopoetic system, liver and kidneys.

EXHIBIT 4.4: Number of Additional People Expected to Incur Health Damage from Substitution of Delta with Fenox on Wheat, Oats, and Barley Crops (Given in number per year for 1974-1978)

Entity Incurring Health Damage	Type of Health Damage										
	Acute Injury						Chronic Injury				
	Morbidity										
	Ocular Exposure Hazard	Dermal Exposure Hazard	Oral Exposure Hazard	Inhalation Exposure Hazard	Systemic Poisoning	Mortality (Death)	Mutagenic Hazard	Terato-genic Hazard	Oncogenic* Hazard	Reproductive Impairment	Physiologic Malfunction Hazard*
Occupational Health Damage to:											
Pesticide R&D Manufacturing and Formulation Workers	5-7	3-4	0	0	0	0	0	0	0	0	0
Pesticide Transport Personnel		Not determined but assumed to be negligible based on discussions with OPP personnel									
Field Workers and Other Farm Personnel	373-374	146-147	0	0	0	0	0	0	0	0	0
Commercial Farm Applicators	1-2	0-1	0	0	0	0	0	0	0	0	0
Professional Non-Farm Applicators (FCO's, government employees, etc.)	na	na	na	na	na	na	na	na	na	na	na
General Public Health Damage to: Household Users of Pesticides (through direct exposure)	na	na	na	na	na	na	na	na	na	na	na
Society as a Whole (through indirect exposure)	0	0	0	0	0	0	0	0	0	0	0

na = not applicable

*In particular, with respect to central nervous system, hematopoetic system, liver and kidneys.

In further assessing these additional health damages, the next step is to determine the monetary value of these damages. This is a difficult task and additional data concerning the age and sex of the subpopulations exposed, the levels of injury at which they will seek medical advice and/or treatment, and the levels of injury at which they will lose time from work, are just a few of the factors which must be considered. For example, two different people exposed dermally to the same degree to a pesticide may react differently. One may seek medical advice, apply some medication and stay home for a day, while the other may go to the drugstore, buy some over-the-counter medication, and not stay home from work. Without increased efforts into examining these processes, monetary estimates of the health hazards would be misleading. A number of people have been doing work in this area,* and, therefore, efforts in this case study were directed to quantifying, in non-dollar terms, the types of hazards that would result from exposure to a pesticide. Nevertheless, this type of analysis is recommended for all benefit-cost analyses, and a monetary evaluation of health costs should be broken out for specific viewing by the decision-maker, whenever possible. This provides the additional advantage of clearly defining what is meant by each hazard term.

In this particular hypothetical case study, one may argue that the value of these additional health damages have already been accounted for in the measure of the change in consumers' surplus. This is explained in the following way. Additional health damages are only incurred by the occupationally exposed. Assuming that these people realize the risks of their profession, they will demand compensation in terms of salary, medical insurance, pensions, etc. These additional health costs are borne by the employers of the occupationally exposed and therefore will be reflected in the change in price of the pesticide, the change in cost to apply the pesticide, the change in cost to harvest the crop, and finally the change in crop price to the consumer. Consequently, in the absence of additional health damages to these people, the change in consumers' surplus would be greater because the change in price paid by the consumer for the crop would be smaller. Hence, the change in consumers' surplus does, in fact, account for the additional health damage to the occupationally exposed.

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*For example, see Dorothy Rice, Estimating the Costs of Illness, Health Economics Series #6, DHEW, 1966 (PHS Publication No. 947-6); Acton, Jan, Evaluating Public Programs to Save Lives: The Case of Heart Attacks, RAND Corporation, January, 1973 (includes an extensive bibliography); and Mushkin, S., "Health As An Investment," Journal of Political Economy, Vol. 7, No. 5, Part 2, October, 1962.

Furthermore, this change in consumers' surplus will account for all additional health damage if the following assumptions hold:

- The occupationally exposed are aware of the risks,
- They willingly accept them,
- They demand compensation for assuming the risks, and
- They receive adequate compensation.

In all probability, the four assumptions will not hold for all those occupationally exposed. Manufacturing and formulating workers and commercial farm applicators are probably aware of the risks. Field workers and other farm personnel should be aware because of required warnings necessary under the EPA "Worker Protection Standards for Agricultural Pesticides" (40CFR170). With respect to the other three assumptions, it is difficult to tell to what extent the occupationally exposed accept the risks, demand compensation, and receive adequate compensation. Assuming that they do not receive adequate compensation, there would be additional health costs not embodied in the change in the consumers' surplus measure. Therefore, all one can say is that balanced against the change in the consumers' surplus measure is some unknown value of the additional health costs incurred by the occupationally exposed not already accounted for in the change in the consumers' surplus measure.

Emphasis is again needed that to more adequately present the situation to a decision-maker, health costs should be valued and separated out for specific viewing if possible. If a portion or all of these net health costs are embodied in the change in the consumers' surplus measure, this can be so stated so that double-counting is avoided.

4.4 Net Health Benefits

Health benefits from substituting Delta with Fenox on wheat, oats, and barley accrue to society in the form of a more healthful, more productive and more content population. These result from an increased food supply caused by an increased yield in these three crops.

From the agricultural impacts analysis in Chapter 3.0, it is estimated that in 1973 an additional 22.5 million bushels of wheat, 32.0 million bushels of oats, and 10.2 million bushels of barley would have been produced, if Fenox had been substituted for Delta.

In 1978, it is estimated that if Fenox is not registered and Delta is continued to be used, the decrease in wheat, oats, and barley production will be 26.6 million bushels, 38.2 million bushels, and 12.1 million bushels, respectively.

Although it is difficult to translate the net benefits (from the increased food production generated from the use of Fenox rather than Delta) into monetary terms, in this case one can argue that they are already accounted for in the change in the consumers' surplus measure. It is assumed that society perceives that there are health benefits associated with an increased food supply as a result of using Fenox rather than Delta on wheat, oats, and barley. Moreover, these additional health benefits are nutritional in nature and only accrue to those who consume wheat, oats or barley products. Therefore, they receive a value from this increased food supply in excess of what they pay for wheat, oats or barley products. Hence, a part of the change in consumers' surplus represents the value members of society put on the additional nutritional health benefits resulting from this increased food supply when Fenox is substituted for Delta and used on wheat, oats, and barley.

Once again, it would be more desirable to separate out these net benefits and show them separately to the decision-maker with the statement that they are already accounted for in the change in the consumers' surplus measure. In this way, they will not be added to the change in the consumers' surplus measure, and double-counting will be avoided.

5.0 ENVIRONMENTAL IMPACTS

5.1 Introduction

Previous chapters of this case study have described how to apply a series of algorithms or submodel components, to calculate the agricultural impacts and health effects of Fenox when compared with its next best alternative Delta. Both are fabricated herbicides having certain assigned features similar to the phenoxy category presently in wide use (e.g., 2,4-D; 2,4,5-T; MCPA). Furthermore, in this chapter, Fenox and Delta are assumed to be similar in all respects, except in their toxicity to birds and fish, as indicated later in the chapter. These pesticides have been in use for some years and have been widely studied.*

Although phenoxy herbicides are characterized by an acid chain, and in some chemicals by chlorine attachments to the organic ring, the general conclusion of published studies has been that these herbicides disappear from the environment within a few months after application and that they are not found to accumulate to high levels in various biological systems, as is the tendency of the organochlorine insecticides. The present report concentrates on possible year-to-year effects and does not assign a high persistence to the hypothetical herbicides Delta and Fenox.

The environmental effects submodel which is applied in this chapter to analyze the change in environmental impacts if Fenox is substituted for Delta has been described in Volume I of the report, and consists of three major components:

- Transport and accumulation component,
- Biological impacts component, and
- Environmental costs component.

As noted in Volume I, some pesticides have inadvertent or incidental benefits, but these are assumed to be minor or negligible for both Delta and Fenox, and the major question is: What are the net environmental costs of this hypothetical herbicide Fenox when compared to its next

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*NSF Advisory Panel on 2,4,5-T.

best alternative Delta? Furthermore, as in the agricultural impacts analysis, data for two years -- 1973 and 1978 -- are presented throughout the analysis. However, in the monetary evaluation of fish and bird damage, data for the years 1974 through 1977 are also determined and their values, along with the 1978 value, are discounted back to their value in 1974.

5.2 Transport and Accumulation

The non-crop environment is impacted by pesticides without regard to the crop on which they are applied. Therefore, the total pounds applied to the three different crops were divided by the total acreage of the combined crops to obtain an average rate of application per acre for each region (see Exhibits 5.1 and 5.2). A more precise approach would be to determine average application rates for each region and each crop. However, it was felt that a regional level analysis would be sufficient here as it partially reflects crop differences.

Within a short time (hours) after the application of a herbicide, it is either absorbed into a plant, absorbed into the soil, or washed into some hydrologic system present at the site of application. Amounts absorbed into plants tend to disappear within days, so that the present study assumes that all herbicides applied in a given year eventually impinge on the soil or water near the application site.

The movement of herbicides from fields into an hierarchical hydrologic system is highly complex, and a somewhat detailed modeling approach is described in Attachment 5.1 to this chapter. A much simplified estimation procedure is to directly relate amounts of herbicide applied to residues found in bodies of water, and to apply the ratios as needed to forecast future residues (see Exhibits 5.3, 5.4, 5.5, and 5.6). The drift factors in Exhibit 5.4 are substitutes for a meteorologic model which would calculate amounts of spray blown into water.

After subtracting drift and runoff amounts, the remaining herbicide is assigned as residue in soil. The residues of Exhibit 5.7 reflect the average decline in amount applied per acre shown in Exhibit 5.2, a phenomenon due to a forecast of increased acreage described in the agricultural impacts chapter above.

EXHIBIT 5.1: Amounts of Fenox or Delta Applied by Regions on Selected Crops*

		Data in Hundreds of Pounds									
		North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific
1973	Wheat	738	3,132	8,254	4,024	1,162	1,072	2,548	1,738	1,476	1,332
	Barley	70	258	116	956	290	56	--	194	612	530
	Oats	112	192	1,572	530	94	102	518	220	34	38
	Total	920	3,582	9,942	6,410	1,546	1,230	3,066	2,152	2,122	1,900
1978	Wheat	874	3,708	9,792	5,824	1,378	1,270	3,006	2,044	1,746	1,576
	Barley	82	308	134	1,136	340	64	--	230	722	626
	Oats	162	226	1,866	628	112	122	614	258	40	46
	Total	1,118	4,242	11,792	7,588	1,830	1,456	3,620	2,532	2,508	2,248

*See Exhibit 6.10 of Volume I of report. This is calculated as AA_{ijkp} = Amount of pesticide k applied in region i between j-1 and j to crop p, and is equal to (the application rate of pesticide k in region i at time j to crop p) times (the number of acres of crop p treated with pesticide k in region i at time j).

Application rates for Fenox or Delta are the same for each year: 0.90 lbs/acre for wheat; 0.46 lbs/acre for barley; and 0.20 lbs/acre for oats (see Chapter 3.0 on agricultural impacts). The number of acres treated with Fenox or Delta is contained in Exhibit 3.8 of the agricultural impacts chapter.

EXHIBIT 5.2: Calculation of Average Application Rates for Fenox or Delta (Pounds/acre applied)*

	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta States	South-ern Plains	Moun-tain	Pacific
1973	.60130	.71640	.57534	.62844	.64686	.67582	.56568	.62376	.67580	.67376
1978	.57040	.71656	.57522	.62814	.64664	.67408	.56474	.62364	.67602	.67306

*Pounds/acre applied = AA_{ijk}/CT_{ijk} = (amount of pesticide k applied in region i between j-1 and j) ÷(total acres of land treated by pesticide k in time j and region i). AA_{ijk} is given in Exhibit 5.1 and CT_{ijk} is given in Exhibit 3.8 of the agricultural impacts chapter.

EXHIBIT 5.3: Calculation of Runoff Factors (ROF_{ik}) for Organochlorine Insecticides by Region

	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	United States Average
Application rate (A) lbs/acre active ingredient*	10.633	0.674	1.064	0.559	5.422	6.635	3.605	1.245	0.880	0.654	3.076440
(A') ppm**	5.317	0.337	0.532	0.280	2.711	3.318	3.303	0.623	0.440	0.327	1.538220
(B) Water residuals*** (ppm x 10^6)		194.05	36.00			33.20	468.50		59.79		158.3080
(B)/(A')**** Runoff factor (ROF_{ik}) (10^6) a unitless proportion i = region; k = pesticide		5758.16	67.67			10.01	259.92		135.89		1246.33 ****

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*Three insecticides: Aldrin, Dieldrin, and DDT applied in 1971. From P. A. Andrilenas, et al., Farmers' Use of Pesticides in 1971: Quantities, USDA, ERS, Agricultural Economic Report No. 252, Washington, D.C., 1974, Tables 13 and 15, pp. 46, 51.

**Pound per acre ÷ 2 = ppm.

***Edwards, C. A., "Pesticide Residues in Soil and Water," in C. A. Edwards, ed., Environmental Pollution by Pesticides, London, Plenum Press, 1973, pp. 440-441. Totals for three insecticides applied in selected years, 1966-1971.

****Use United States average for all regions. See also C. A. Edwards, Persistent Pesticides in the Environment, Cleveland, Chemical Rubber Company Press, 1973, p. 35.

EXHIBIT 5.4: Calculation of Water Application and Drift Factor (APW_{ijk})*

	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta States	South-ern Plains	Moun-tain	Pacific	Total United States
(A) Water Surface (sq. mi.)	6,851	7,868	2,133	3,705	6,597	7,004	5,172	6,341	7,840	4,751	58,262**
(B) Land Surface (sq. mi.)	175,203	190,570	257,756	303,498	193,626	193,096	144,171	330,916	856,047	319,115	2,963,998
.01 A/B APW_{ijk}	.000391	.000413	.000083	.000122	.000341	.000363	.000359	.000192	.000092	.000149	.000197

*APW_{ijk} = water application and drift factor in region i at time j for pesticide k (a unitless proportion) = (.01) (acres of water surface in region i)/(acres of land surface in region i); j = time and k = pesticide.

**(58,262 sq. mi.) (640 acres/sq. mi.) = 37,287,680 acres.

EXHIBIT 5.5: Herbicide Residue (Fenox or Delta) in Water* (PLW_{ijk}, in ppm)

		North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta States	South-ern Plains	Moun-tain	Pacific	
ROF_{ik} + APW_{ijk}**		.00164	.00166	.00133	.00137	.00159	.00161	.00161	.00144	.00134	.00140	
Amount Applied Converted to ppm***	1973	.30065	.35820	.28767	.31422	.32343	.33791	.28284	.31188	.33790	.33688	
	1978	.28520	.35828	.28761	.31407	.32332	.33704	.28237	.31182	.33801	.33653	Total
PLW_{ijk}: Residue in Water****	1973	.00050	.00059	.00038	.00044	.00052	.00054	.00046	.00046	.00046	.00048	.00483
	1978	.00046	.00059	.00038	.00044	.00052	.00054	.00046	.00046	.00046	.00048	.00479

*The change in herbicide residue in water if Fenox is substituted for Delta is assumed to be zero.

**The United States average for ROF_{ik} is used (see Exhibit 5.3) and regional figures for APW_{ijk} are used (see Exhibit 5.4).

***Source: Exhibit 5.2 and conversion factor of one-half pound/acre = ppm.

****$PLW_{ijk} = [ROF_{ik} + APW_{ijk}]\ [(CV)\ (AA_{ijk}/CT_{ijk})]$

CV is a constant to convert pound/acre to ppm: one-half pound/acre = ppm.

EXHIBIT 5.6: Simplified Calculation of Accumulation of Fenox or Delta in Soil, 1973-1977*

$$RSDL_{ik} = [(\frac{1}{J})(\sum_{j=1}^{J} AA/CT) - (\frac{1}{J})(\sum_{j=1}^{J} AA/CT)(ROF_{ik} + APW_{ijk})]\ [1 - DF_{ik}]$$ for region i, year j, herbicide k

[Total accumulated] = [Net application to soil] [1 - Degradation rate]

[Net application to soil] = [Annual average amount] [Number of years] - [Annual average amount]

[Runoff rate] [Number of years]

	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta States	South-ern Plains	Moun-tain	Pacific
Average application per year (ppm)	.29293	.35824	.28764	.31415	.32338	.33748	.28261	.31185	.33785	.33671
Runoff + drift loss for five years, ppm**	.00240	.00300	.00192	.00216	.00258	.00250	.00240	.00224	.00226	.00236
Net application	.29053	.35524	.28572	.31199	.32080	.33498	.28021	.30961	.33559	.33435
Residue after degradation***[(Net application) x (1 - DF_{ik})]	.01453	.01776	.01429	.01560	.01604	.01675	.01401	.01548	.01678	.01672

*The change in accumulation in soil if Fenox is substituted for Delta is assumed to be zero.

**Runoff rate = $ROF_{ik} + APW_{ijk}$ (from Exhibit 5.5).

***DF_{ik} = degradation factor = 0.95 in one year for Delta or Fenox (see Volume I of report, Exhibit 6.7). Therefore, the amount remaining = $(1 - DF_{ik})$ = 0.05 for each year. For Fenox and Delta, PLS_{1973} (i.e., soil pollution level in 1973) is assumed to be zero for all regions.

EXHIBIT 5.7: Herbicide Residue (Fenox or Delta) in Soil, Per Acre*

		North-east	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific
Application (ppm) (see Exhibit 5.5)	1973	.30065	.35820	.28767	.31422	.32343	.33791	.28284	.31188	.33790	.33688
	1978	.28520	.35828	.28761	.31407	.32332	.33704	.28237	.31182	.33801	.33653
Runoff amount (ppm) (PLW) (see Exhibit 5.5)	1973	.00050	.00058	.00038	.00044	.00052	.00054	.00046	.00046	.00046	.00048
	1978	.00046	.00058	.00038	.00044	.00052	.00054	.00046	.00046	.00046	.00048
Previous accumulation (ppm) (RSDL) (see Exhibit 5.6)	1973	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	1973-1977	.01453	.01776	.01429	.01560	.01604	.01675	.01401	.01548	.01678	.01672
Net total in soil**	1973	.30015	.35761	.28729	.31378	.32291	.33737	.28238	.31142	.33744	.33640
	1978	.22927	.37545	.30152	.32923	.33884	.35325	.29592	.29592	.35433	.35277

*The change in herbicide residue in soil if Fenox is substituted for Delta is assumed to be zero.
**Soil residue = application rate - runoff amount + previous accumulation.

5.3 Impacts on Biological Systems

The natural accumulation of herbicides in fish and wildlife occurs both due to direct absorption and ingestion, as well as due to accumulation by means of the food chain. Conceptually, the food chain accumulation is much more complex and difficult to assess, but when approached from a modeling point of view, the two types of phenomena tend to merge. For example, suppose an aquatic herbicide is applied to some water hyacinths, portions of which are then eaten by various species of water fowl. Some of the herbicide has been absorbed systematically by the plant; but some of the chemical adheres temporarily to the leaves, until it is washed off. It is possible to assert that the herbicide which was absorbed into the plant was accumulated in the ducks as part of their food chain, while the herbicide which was on the surface of the leaves was "ingested directly."

Similar phenomena can be identified with fish, which absorb herbicides directly through their gills, as well as by eating microorganisms which have absorbed the chemicals. In order to obtain a simple algorithm for fish accumulation, data on concentrations of herbicides in fish tissue and in water were averaged over a period of time and over several geographic locations.* The data on concentrations in fish were in the form of concentration factors, and an average of these factors was used to assess the feasibility of using such factors for herbicide accumulation. For the data on insecticides, a reverse calculation of water concentrations derived from fish calculations is shown in Exhibit 5.8. Assuming the concentration factors for phenoxy herbicides would be similar, the fish concentration factor was then applied to water concentration data from previous calculations (Exhibit 5.5, above), to obtain regional fish concentrations shown in Exhibit 5.8, below.

These data, shown in parts per million, should probably be interpreted as milligrams per kilogram of fish weight. The process of accumulation of these residues is much more complex, as noted above,

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*Edwards, C. A., Persistent Pesticides in the Environment, Cleveland, Ohio, Chemical Rubber Company Press, 1971, Table 12, p. 8; and Menzie, C. M., "Effects of Pesticides on Fish and Wildlife," F. Matsumura, et al., eds., Environmental Toxicology of Pesticides, Table 8, p. 497.

EXHIBIT 5.8: Calculation of Herbicide Concentration (Fenox or Delta) in Fish*

$CFH_{ijkp} = (KF_{jkp})\ (PLW_{ijk})$ (formula from Volume I of report, Exhibit 6.11)

$CFH_{ijkp} = 7.40523$, fish tissue residues, Table 12, p. 8, C. A. Edwards, Persistent..., Cleveland, Ohio, Chemical Rubber Company Press, Table 11, p. 28 (average of 65 values, amount of DDT in ppm). For lower ratios ≈ 1.30, see T. Nakatsugawa and P. Nelson, "Studies of Insecticide Detoxification in Invertebrates...," in F. Matsumura, *et al.*, eds., Environmental..., Academic Press, 1972, p. 505.

$KF_{jkp} = 4831.0$, concentration factor, average of seven organochlorine insecticides, Table 8, p. 497, data from studies dated 1964-69. Menzie, C. M., "Effects of Pesticides...," in F. Matsumura, *et al.*, eds., Environmental Toxicology..., pp. 487-500.

$7.40523 \div 4831.0 = 0.0015$ ppm; this is a typical residue level found in water (see Exhibit 5.5).

Therefore, regional concentrations $(CFH_{ijkp}) = (4831.0)\ (PLW_{ijk})$:

		Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta	Southern Plains	Mountain	Pacific
Herbicides Residues (ppm)	1973	2.4155	2.8503	1.8358	2.1256	2.5121	2.6087	2.2223	2.2233	2.2223	2.3188
	1978	2.2223	2.8503	1.8358	2.1256	2.5121	2.6087	2.2223	2.2223	2.2223	2.3188

*The change in herbicide concentration in fish if Fenox is substituted for Delta is assumed to be zero.

than the use of a single concentration factor implies. Similarly, the variability in concentration levels is overlooked in the time period and geographic averages used here. Both fish weight levels and herbicide concentration levels rise and fall seasonally, and regionally, with greater variability than is reflected in the two single years and the ten regions shown in Exhibit 5.8.

For the calculation of herbicide concentrations in birds, a specific research effort on herbicide concentrations in gallinules was used. Although this procedure resulted in the less detailed depiction of accumulation mechanisms than a more explicit food chain model would allow, these research data were among the few data available which dealt directly with herbicides, instead of organochlorine insecticides. As noted above, herbicides, especially the phenoxy type, degrade rapidly in soil, and are thought to sink rapidly in bodies of water, so that data on their transportation in fish and wildlife are lacking, and coefficients for concentration are only available if they are based on estimates for insecticides. The research published by Schultz and Whitney,* however, is an exception. Data from this study are shown in Exhibit 5.9, along with the results of applying the Loxahatchie "uptake coefficient" to the application rates from Exhibit 5.2 above. The resulting bird concentrations are in units of milligrams per kilogram of bird tissue. Emphasis is needed here that a much more specific model of this process would be desirable. In such a model, the application rate in lbs/acre would be converted to density in water and then into residues in tissue using a biological uptake factor. Such a model would be more realistic but would require large amounts of additional data to develop.

As described in Volume I of this report, there are three types of fish and wildlife damages which typically occur as a result of herbicide application: acute (immediate) toxic effects; accumulation (chronic) toxic effects; and reproductive disruption due to genetic damage or to some damage to reproductive mechanisms. For fish, birds, and mammals, a matrix of three rows and three columns would be ideal for analyzing these types of effects, or population reductions. Lack of data, however, make it impossible to fill in all nine cells of such a matrix,

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*Schultz, D. P., and E. W. Whitney, "Monitoring 2,4-D Residues at Loxahatchie National Wildlife Refuge," Pesticide Monitoring Journal, Vol. 7, No. 3/4, March, 1974, Tables 1 and 4.

EXHIBIT 5.9: Summary of Herbicide Uptake (Fenox or Delta) by Gallinules*

Amount of Application	Residue in Breast Muscle (mg/kg)	Residue in Liver (mg/kg)	Total Residue (mg/kg)
4 lbs/acre (2 applications 2 months apart)	0.300	0.675	0.975

$$\text{Uptake coefficient} = \frac{0.975 \text{ mg/kg}}{4 \text{ lb/acre}} = 0.243750^{**}$$

		North-east	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta	Southern Plains	Mountain	Pacific
Application rates (lbs/acre) (see Exhibit 5.2)	1973	.60130	.71640	.57534	.62844	.64686	.67582	.56568	.62376	.67580	.67376
	1978	.57040	.71656	.57522	.62814	.64664	.67408	.56474	.62364	.67602	.67306
Concentration in water fowl = (application rate) x (uptake coefficient) (ppm)	1973	.14657	.17462	.14024	.15318	.15767	.16473	.13788	.15204	.16473	.16423
	1978	.13904	.17406	.14020	.15311	.15762	.16431	.13766	.15201	.16478	.16406

*The change in herbicide concentration in birds if Fenox is substituted for Delta is assumed to be zero.

**Source: Schultz, D. P., and E. W. Whitney, "Monitoring 2,4-D Residues...," Pesticide Monitoring Journal, Vol. 7, No. 3/4, March, 1974, Tables 1 and 4, pp. 146, 152.

so that the effects which could be assessed are shown in Exhibits 5.10, 5.11, and 5.12. These effects include additional chronic and reproductive effects to fish and additional chronic effects to birds if Fenox is substituted for its next best alternative Delta.

The calculation of additional acute damages to fish is based on the lethal concentration concept, which has been widely researched (see source reference in Exhibit 5.10). The calculations shown in Exhibit 5.10, and in Volume I of this report, assume that if the entire biomass of freshwater fish in the United States receives exposure to some given level, then some proportion of the individual fish will receive an equivalent to, or an excess of, the 50 percent lethal concentration, and half of those receiving that level of dose will die. It is further assumed that the proportion which experience the LC_{50} will be equal to the proportion of the LC_{50} which is found in the waters of the United States, averaged over geographic areas. These above assumptions can be debated and as more data become available they can be refined.

Further assumptions were necessary to estimate the population of fish of major species which exists in the United States. A more detailed approach to the estimation of fish populations is shown in Attachment 5.2 of this chapter.

5.4 Values of Ecologic Damages

The Statistical Abstract of the United States* gives data which are useful in assessing the value of the fish and wildlife killed and not produced each year due to pesticides. These data represent expenditures by public agencies, including Federal, state, and local, to maintain wildlife and wildlife habitats. Ideally, costs of wildlife should be divided into costs of maintaining habitats, and costs of restocking, and then these costs could be weighted according to the amount of each that was incurred due to pesticide damages. The data available, however, as shown in Exhibit 5.13, only enable a total cost of maintenance, and

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*U. S. Bureau of the Census, Statistical Abstract of the United States, 1974, W. Lerner, ed., Washington, D.C., Superintendent of Documents, 1974.

EXHIBIT 5.10: Summary of Additional Population Damages to Fish in Fenox is Substituted for Delta

Assume LC_{50} = 106 ppm for Delta

Source: Average of 23 studies of 2,4-D and 2,4,5-T compiled in J. M. Lawrence and E. B. Hollingsworth, Supplement to Aquatic Herbicide Data (supplement to Agricultural Handbook 231), Washington, D.C., USDA, 1969.

Hypothetically assume LC_{50} = 53 ppm for Fenox

Concentration in Water (ppm) (see Exhibit 5.5)	1973	.00483	
	1978	.00479	
Net acute effect (net population kill factor)	1973	.0000455	.00483/53 - .00483/106 = .0000455
	1978	.0000452	.00479/53 - .00479/106 = .0000452 (see Volume I of report, Exhibit 6.12)
Population total, each year*		37,287,680,000	
Additional number of fish killed, if Fenox is substituted for Delta	1973	1,700,000	
	1978	1,682,000	

*Assumption: Federal and state agencies stock enough to maintain constant population, regardless of number caught or killed by pesticides. Assume carrying capacity of 1,000 fish per acre of water (see Exhibit 5.4). However, a more precise approach to "standing crop" is shown in Attachment 5.2 to this chapter.

EXHIBIT 5.11: Summary of Additional Reproductive Effects on Fish if Fenox is Substituted for Delta

Net reduction of fish population in year j = $[CFH_{ijkp}/104]\ [.035\ (FPP_{ijk})]$*

Concentration in fish tissue (CFH_{ijk}) average for 10 regions (see Exhibit 5.8)	1973	2.33337	Therefore, $CFH_{ijk}/104 = .02244$
	1978	2.31405	Therefore, $CFH_{ijk}/104 = .02225$
Fish production, each year (FPP) (see Exhibit 5.10)		37,287,680,000	Therefore, (FPP) (.035) = 1,305,069,000
Net number of fish not produced due to reproductive impairment if Fenox is substituted for Delta	1973	(1,305,069,000) (.02244) = 29,286,000	
	1978	(1,305,069,000) (.02225) = 29,038,000	

*This formula is from Volume I of the report (Exhibit 6.12) and hypothetically assumes that an intake of 104 mg/kg/year of Delta or 52 mg/kg/year of Fenox would result in a loss of 3.5 percent of next year's population. These assumptions imply that a net reduction of 3.5 percent would result from an exposure of 104 mg/kg/year if Fenox is substituted for Delta.

EXHIBIT 5.12: Summary of Additional Effects of Gallinules if Fenox is Substituted for Delta

Assume LD_{25} = 21.50 mg/kg/day for 30 days for Delta.

Source: Matsumura, F., "Biological Effects of Toxic Pesticidal Contaminants...," in F. Matsumura, et al. (eds.), Environmental Toxicology of Pesticides, New York, Academic Press, 1972, p. 536.

Hypothetically assume LD_{25} = 10.75 mg/kg/day for 30 days for Fenox.

Number of birds killed = [(Average residue in tissue)/LD_{25}] [(1/4) (Total bird population)]
(formula from Volume I of report, Exhibit 6.12)

Total bird population = 7.4214 birds per acre of water, from "Ecological Factors Affecting Waterfowl Production," Bureau of Sport Fisheries and Wildlife, U. S. Department of the Interior, Washington, D.C., p. 8 (Resource Publication Series No. 98), Tables 5 and 10, pp. 19, 25.

Average residue in tissue (see Exhibit 5.9)	1973	.155589
	1978	.154745
Total bird population (see Exhibit 5.4 for water area)		276,726,788
Net number of birds killed if Fenox is substituted for Delta	1973	501,000
	1978	498,000

Assume: Stocking by government agencies prevents significant population decline.

EXHIBIT 5.13: Cost of Maintaining Wildlife Population*

FC = Total Federal expenditures (1973) $297,900,000

Source: 1974 Statistical Abstract, Table 332.

Camper days + hunter days + fisher days = 112,839,000 + 203,689,000 + 706,187,000 = 1,022,715,000 recreation days

Source: 1974 Statistical Abstract, Tables 336, 337, 339, and 345.

$$\text{CRD} = \text{cost per recreation day} = \frac{\text{FC}}{(\text{camper days} + \text{hunter days} + \text{fisher days})} = \frac{\$297{,}900{,}000}{1{,}022{,}715{,}000 \text{ recreation days}} = \$0.29128$$

*Based on formula in Volume I of report, Exhibit 6.16.

an average cost per recreation day, to be calculated. The next step is to calculate the number of wildlife obtained, or "experienced" during each recreation day. These calculations are shown in Exhibit 5.14. Implicitly assumed in this calculation is the idea that experiencing one wildlife is equivalent to experiencing either two birds or two fish. This is a philosophical issue not to be resolved here and the assumption can be debated. This exhibit also shows the average value of each animal (either bird, fish or wildlife) experienced by each person each recreation day.

Finally, Exhibit 5.15 shows the additional dollar value of fish and bird damages, based on numbers of additional fish and birds lost due to the use of Fenox rather than Delta, as shown in Exhibits 5.10, 5.11, and 5.12 above. It should be emphasized that the values shown in Exhibit 5.15 are severe underestimations, due to the lack of total costs of restocking, and due to the lack of good estimates of total mammals, including both small and large game, lost due to accumulation of Fenox rather than Delta in the food chain. Volume I of this report suggested some ways of approaching the assessment of these values, but data limitations have thus far prevented the application of such methods.

EXHIBIT 5.14: Value of Wildlife*

1. BRK = number of birds killed per hunter day = 1.3429

   Source: Chamberlain, E. B., et al., Waterfowl Status Report, 1972, Washington, D.C., U. S. Government Printing Office, 1972, Stock No. 241000353, Bureau of Sport Fisheries and Wildlife, Special Scientific Report Series No. 166, Wildlife, U. S. Department of the Interior, Table C-11, p. 143.

2. FSC = number of fish caught per fishing day = 303,488,443 fish stocked ÷ 706,187,000 fisher days = 0.42976

   Source: Number of fish caught is approximately equal to the number stocked, see U. S. Department of the Interior, Propagation and Distribution of Fishes from National Fish Hatcheries for the Fiscal Year 1973, Fish Distribution Report No. 8, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, 1974, p. 27.

   Number of fishing days from 1974 Statistical Abstract, Table 345.

3. OWK = number of other wildlife killed:

Dall and Stone Sheep	2,071	(1971)
Grizzly and Brown Bear	1,323	(1971)
Bighorn and Desert Bighorn Sheep	49	(1971)
	529	(1971)
Total	3,972	

$$\text{Average per hunter day} = \frac{3,972}{203,689,000} = .0000195$$

Source: Brakefield, T.. "Bighorns and Bears," Part 2, The American Hunter, Vol. 2, No. 8, August, 1974, pp. 63-66; and Part 1, Vol. 2, No. 7, July, 1974, pp. 63-67.

EXHIBIT 5.14 (continued)

4. OWL = wildlife stocked in 1973

Deer	738	Small game	181
Antelope	285	Turkey	733
Elk	301	Pheasants	230
Mountain sheep	19	Grouse	40
Other big game	31		
Fur animals	128	Total, all types	2,686

Source: U. S. Department of the Interior, Fish and Wildlife Service, Federal Aid in Fish and Wildlife Restoration, Washington, D. C., Wildlife Management Institute and Sport Fishing Institute, 1974, Table 13, p. 32.

5. Animals experienced per person day = $[(2)\ (\text{BRK} + \text{FSC})] + [(\text{OWK} + \text{OWL})/\text{recreation day}] = 3.54533$

6. Cost/animal = $\dfrac{\text{CRD}}{\text{animals per person day}} = \dfrac{\$0.29128}{3.54533} = \$0.08216$

*Based on formula in Volume I of report, Exhibit 6.16.

EXHIBIT 5.15: Additional Value of Fish and Bird Damages if Fenox is Substituted for Delta*

		Number	Total Value
Birds	1973	501,000	$ 41,000
	1978	498,000	$ 41,000
	5-year total (1974-1978)**	2,500,000	$ 205,000
	5-year total (1974-1978) discounted back to 1974***		$ 171,000
Fish	1973	1,700,000 + 29,286,000	$ 2,546,000
	1978	1,682,000 + 29,038,000	$ 2,524,000
	5-year total (1974-1978)**	154,000,000	$12,664,000
	5-year total (1974-1978) discounted back to 1974***		$10,564,000

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*Source: Exhibits 5.10, 5.11, 5.12, and 5.14 above.

**The years 1974 through 1977 were interpolated and then the years 1974 through 1978 were added together.

***Each of the five years 1974 through 1978 was discounted back to its value in 1974 and then added together. The procedure is fully explained in Exhibit 3.13, with the modification that a discount rate of 10 percent is used because no inflation has been built into the present monetary evaluation.

ATTACHMENT 5.1: Alternative Method to Calculate Environmental Hazard from Surface Runoff of Fenox or Delta

The potential hazard to the environment via surface runoff of pesticides can be estimated by the following four-step procedure:

- Pesticide concentration in the soil according to application rate and soil density,
- A soil runoff factor away from the application site,
- Sediment delivery rate of contaminated soil from the field runoff to a waterway, and
- Calculation of the harmful effects of pesticides entering the waterway, in terms of lost wildlife.

Let C represent the pesticide concentration in the soil in ppm. Therefore:

$$C = (R/M_S) \times 10^6$$

where: R = the given application rate in lbs/acre,

M_S = the mass of the soil which depends upon the volume (V_S) of the contaminated soil and the unit weight of soil (W_S).

Assuming that the depth of concentration ranges from one to six inches and averages three inches, the volume of one acre is then:

$$V_S = (.25 \text{ feet}) (43{,}500 \text{ sq. ft/acre}) = 10{,}890 \text{ cu. ft/acre}$$

The mass of the soil, equal to (V_S) (W_S), can be calculated if W_S or the unit weight of soil is known. W_S generally varies between 85-145 pounds per cubic foot depending upon the level of moisture and the soil type. Therefore, one can assume that W_S averages 100 pounds per cubic foot. Based on application rates for Fenox or Delta of 0.90 lb/acre for wheat, 0.46 lb/acre for barley, and 0.20 lb/acre for oats, the pesticide concentration in the soil is equal to:

$$C = (R/M_S) \times 10^6$$

where: $M_S = (0.25)(43,560)(100) = 1.089 \times 10^6$ lb/acre

or: $C = \dfrac{R}{1.089\,(10)^6 \text{ lb/acre}} \times 10^6 \dfrac{R}{1.089}$

where: R varies from 0.20 to 0.90 lb/acre.

C for each of the three crops treated is shown in Exhibit 5.16.

An average soil loss for cultivated land is available for seven regions in terms of tons per acre (T_A) lost and is shown in Exhibit 5.17. T_A times the acres of wheat, oats, and barley to which Fenox or Delta is applied gives the loss of contaminated soil for each region, in tons, where the contaminated soil contains a concentration of Fenox or Delta equal to C ppm.

A sediment delivery ratio which relates the soil delivered to a waterway to the soil runoff from the crop site can then be calculated. This relationship has been estimated as:

$$\text{Log } D = 1.534 - 0.142 \text{ Log } A$$

where: D = sediment delivery ratio,

A = drainage area in hectares,

and is shown graphically in Exhibit 5.18. The recommended drainage area for use in this calculation should be no larger than Aggregated Statistical Areas (ASAs), of which there are 99 in the continental United States. These areas must then be aggregated by USDA regions in order to estimate the sediment associated with a particular use of Fenox or Delta.

The application of a sediment delivery ratio to the soil loss calculation yields the amount of pesticide-contaminated soil with a concentration level of C ppm which is deposited in waterways. A water solubility factor of Fenox or Delta can then be applied to the delivered volume of sediment which will yield the quality of the water in terms of Fenox or Delta content. Sophisticated models of solubility of pesticides in waterways would include flow, volume, and temperature of the waterways. Given that the phenoxy herbicides have relatively low solubility levels in water -- 620 ppm for 2,4-D at 20° C and 40 ppm for

EXHIBIT 5.16: Pesticide Concentration in Soil Based on Pesticide Application Rate

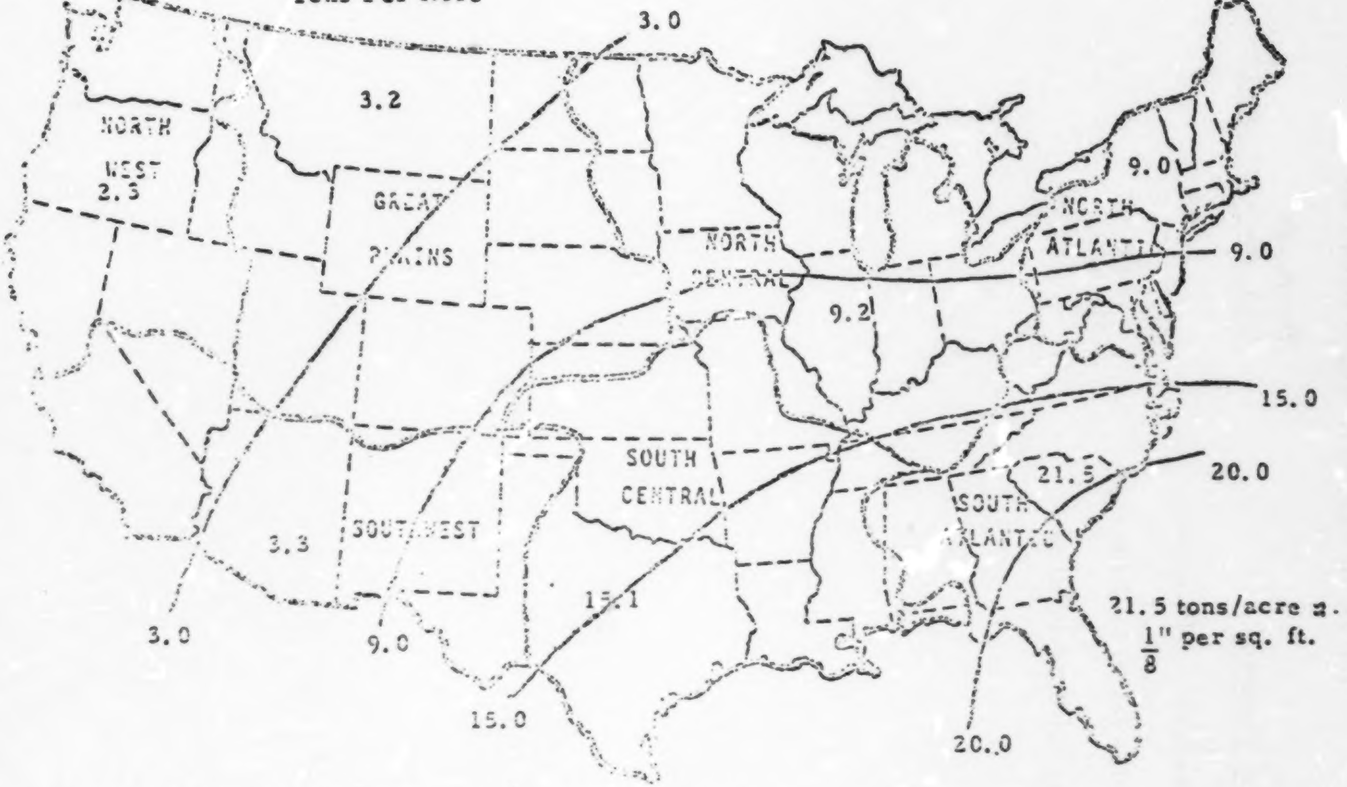
Crop Treated	Pesticide Concentration (ppm)
Wheat (at 0.9 lb/acre)	0.83
Barley (at 0.46 lb/acre)	0.42
Oats (at 0.10 lb/acre)	0.09

280<

EXHIBIT 5.17: Average Soil Loss for Cultivated Land*

1967

Tons Per Acre


3.0
3.2
NORTH WEST 2.3
GREAT PLAINS
NORTH CENTRAL
9.2
NORTH ATLANTIC
9.0
9.0
15.0
20.0
21.5
SOUTH ATLANTIC
SOUTH CENTRAL
SOUTHWEST
3.3
15.1
21.5 tons/acre = $\frac{1}{8}$" per sq. ft.
3.0
9.0
15.0
20.0

*Adapted from Table 14, page 32, Models of Soil Loss, Land and Water Use, Spatial Agricultural Structure, and the Environment, Card Report 49T, the Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa, July 1974.

Reproduced from best available copy.

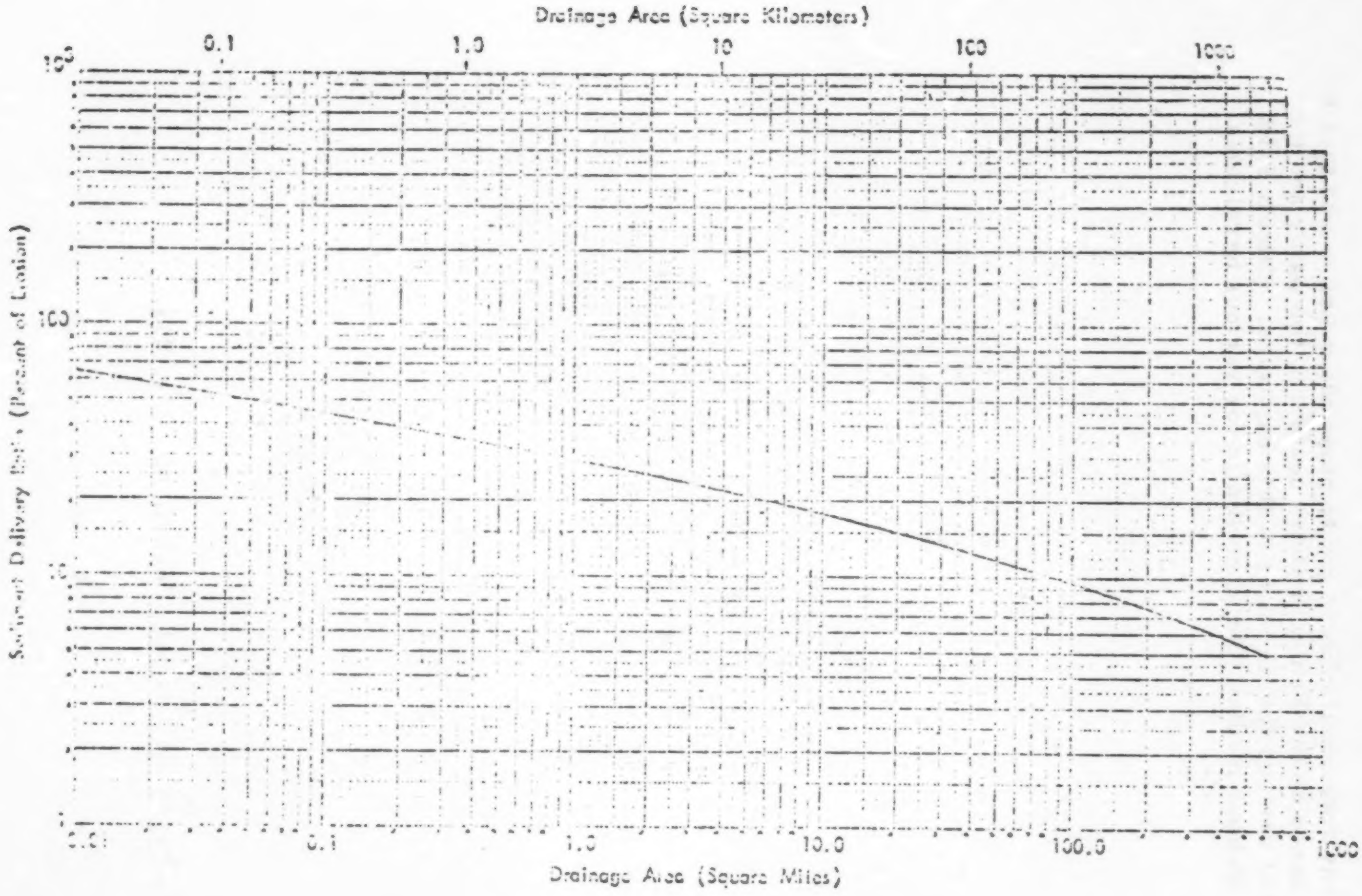


EXHIBIT 5.18: Sediment Delivery Ratio vs. Size of Drainage Area *

*U.S. Department of Agriculture, National Engineering Handbook, Section 3, "Sedimentation", USDA-SCS (1973).

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2, 4, 5-T at 30° C* -- Fenox or Delta can be considered to possess a low solubility level in water.

The environmental effects due to pesticide runoff would then be calculated based on the Fenox or Delta content of the water and the tolerances of various fish in water to this exposure. Exhibit 5.19 shows the 48-hour median tolerance limits for various herbicides.

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*AID, Pesticide Manual, Part II, pp. 201, 211.

EXHIBIT 5.19

48 h Median Tolerance Limits for Herbicides*

Herbicide	Fish tested	48 h TL_m (p.p.m.)	Temp. °C
2,3,5-TBA	bluegill	90	25
"	largemouth bass	55	25
2,3,6-TBA	bluegill	1,750	25
"	largemouth bass	1,250	25
2,4-D	bluegill	375	25
"	largemouth bass	350	25
4-(MCPB)	bluegill	15	25
"	largemouth bass	10	25
4-(2,4-DB)	bluegill	8	25
"	largemouth bass	10	25
ACP-M-569	chinook salmon	155	20
Aminotriazole	coho salmon	325	20
"	largemouth bass	> 1,000	20
Baron	chinook salmon	2·3	20
"	channel cat	6·9	19
C 56	bluegill	30	25
"	largemouth bass	35	25
Chlorax	rainbow trout	1,800	18
"	channel cat	2,367	20
Chlorea	rainbow trout	1,100	18
CIPC	bluegill	12	25
"	largemouth bass	10	25

* Based on the data of Davis and Hardcastle[28]; Bond, Lewis and Fryer[29]; Alabaster[30], and Clemens and Sneed[34].

Table 10—cont.

Herbicide	Fish tested	48 h TL_m (p.p.m.)	Temp. °C
Diquat	chinook salmon	28·5	20
Diuron	coho salmon	16	20
Dowpon	" "	340	20
"	brown trout	210	18
EDB	bluegill	18	25
"	largemouth bass	15	25
Endothal	" "	200	25
"	chinook salmon	136	25
F-98 (Acrolein)	" "	0·08*	20
Hyamine 1622	coho salmon	53	20
Kuron	chinook salmon	1·23	20
Monuron	coho salmon	110	20
Nemagon	bluegill	20	25
"	largemouth bass	20	25
Omazene	chinook salmon	0·33	20
Phygon XL	largemouth bass	0·07	20
"	channel cat	0·14	19
Shell D 50	rainbow trout	210	18
Simazine	chinook salmon	6·6	20
"	rainbow trout	83	18
Sodium TCA	chinook salmon	> 870	20
TCA	channel cat	> 2,000	20

* This value is for 24 h, no figure for 48 h is given in the data.

Reproduced from best available copy.

Source: J. R. Erichsen Jones, Fish and River Pollution, Butterworths, London, 1964.

ATTACHMENT 5.2: A Method for Calculating the Quantity of Fish in Inland Waters by Region

The amount of fishlife in a reservoir, lake or stream can be described in two ways, i.e., carrying capacity and standing crop. Carrying capacity is the maximum poundage of a fish species that a given aquatic habitat may support over a given period of time. This concept describes the potential of the waterway to support fish life, given the biological characteristics of the waterway.

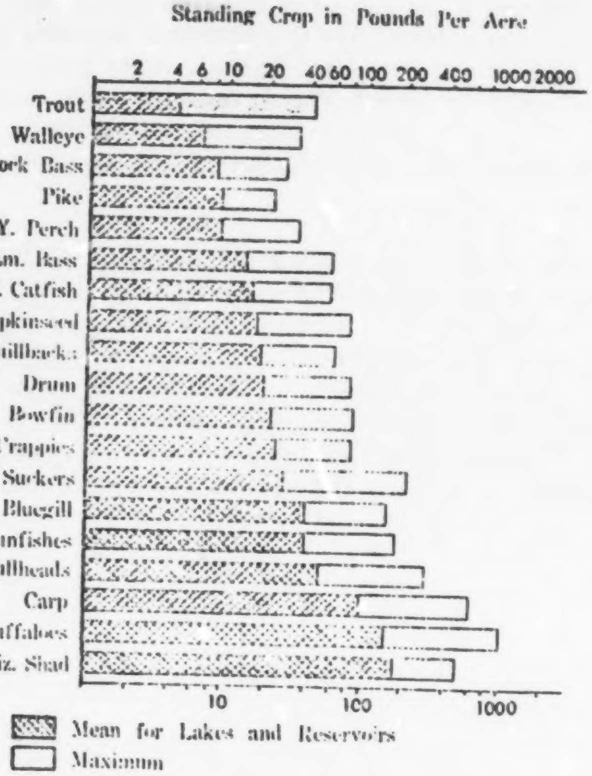
The concept of a standing crop is intended to estimate the actual quantity of fish, usually in pounds per acre, in a body of water at a point in time. In other words, the standing crop estimate is a census of fish at a given moment.

Some general points should be kept in mind while discussing both of these concepts:

- The relationship between the standing crop and the carrying capacity of a body of water is usually unclear.
- The greater the number of species, the larger the standing crop due to a more efficient use of available food.
- Pounds of fish per acre, not fish per acre, is the generally accepted index in order to correct for seasonal variations, e.g., the large number of fish hatched annually which do not survive for a long period of time.
- Carrying capacity is dependent more upon surface area than depth or volume of water.

Exhibit 5.20 shows standing crop in pounds per acre for various species of fish. This exhibit was constructed to show the relative efficiency of the species listed with the realization that these fish generally are seen in combination with other species.

EXHIBIT 5.20



Source: Bennett, George W., Management of Lakes and Ponds, 2nd edition, Van Nostrand Reinhold, New York, 1971.

The average of the mean pounds per acre for the 19 species is approximately 36. This could be easily modified for each region by weighting the mean pound per acre for each species according to the relative popularity of each species. Also, additional species could be included if that type is popular in any one region. This standing crop data can then be applied to the water surface area for each region so that a regional volume of fish, in pounds, can be constructed. Both regional inland water surface area and regional standing crop data are shown in Exhibit 5.21.

Unfortunately, this method overstates the quantity of fish due to the use of total regional water area and because it is unlikely that all the regional bodies of water contain fishlife. However, no inventory of bodies of water containing fish could be found. An alternative method would be to aggregate reservoirs, lakes, and rivers and assume that all fishlife is contained in these three types of water. This is difficult, however, because the standing crop are in terms of area, while reservoirs are generally stated in volume and rivers are described by length.

EXHIBIT 5.21: Regional Water Area and Standing Crop

Region	Inland Water Area* (1,000 acres)	Standing Crop** (1,000 lbs)
Northeast	3,509	126,324
Appalachia	4,222	151,994
Southeast	4,482	161,352
Cornbelt	1,365	49,140
Lake States	5,035	181,260
Delta States	3,310	119,160
Northern Plains	2,371	85,356
Southern Plains	4,058	146,088
Mountain	5,017	180,612
Pacific	3,040	109,440
Total	36,409	1,310,724

*Calculation from 1974 Statistical Abstract, p. 72.

**Calculated as follows: Standing crop = (36 lbs. of fish per acre) (water area in acres).

APPENDIX A

AGRICULTURAL ANALYSIS OF THE USE OF PESTICIDE ALTERNATIVES TO DDT ON SWEET POTATOES, SWEET CORN AND PEANUTS IN 1973 AND 1974

1.0 FORM OF ANALYSIS AND OVERALL CONCLUSIONS

1.1 Background and Agricultural Context

The purpose of this report is to describe certain impacts which the cancellation of the registration for Dichloro Diphenyl Trichloroethane (DDT) has had on the production of certain selected crops. The three crops selected in this analysis, sweet corn, peanuts, and sweet potatoes are three in a series which are part of a general retrospective study conducted by EPA-OPP on the impacts of the 1972 cancellation decision. The general method used in this analysis was to apply components of a general benefit-cost system for chemical pesticide use. The system has been developed in general form into a set of components or submodels which may be selected and applied as needed for any regulatory decision of interest.

The selection of sweet corn, peanuts, and sweet potatoes for this particular effort in the context of a larger review dictated that certain conditions must be considered in the agricultural context of the study:

- The use of DDT on the three crops in both volume and extent,
- The pests involved,
- The alternative pesticides selected after cancellation, and
- The costs of the alternative pesticides.

In addition to the above considerations, the analysis of the use of DDT on sweet potatoes was defined to be the use of DDT on stored sweet potatoes, not sweet potatoes in the field. This particular consideration actually separated the analysis of sweet potatoes from the analysis of the other two crops, making it a different study, but the results are combined into a single discussion in this report.

The overall structure of the report conforms to the components of the general benefit-cost system that were used to analyze the production impacts of the cancellation. These components, which were selected from the more comprehensive "food, feed, and fiber" submodel of the general system, provided the following analyses:

- Prices paid by farmers for pesticides,
- Amounts of pesticides applied, and
- Acres of crops treated by pesticides.

In addition, reviews of the three crop situations with respect to changes in yields and changes in commodity prices were conducted. These reviews indicated that application of model components designed to analyze yield and price treands would not be suitable for these crops, due to extensive grouping of crop data in standard data sources and lack of data for small geographic units (see Chapter 5.0 below).

The agricultural context of the three crops includes a general decline in the domestic production of DDT since its peak in 1963 of 187,782,000 pounds.* However, data on exports indicate that production may be increasing. Exports climbed from 35,424,000 pounds in 1972 to 73,712,000 pounds in 1973. Production data for these two years were not published in order to avoid individual firm disclosures.** In any case, for the last two years published, 1969 and 1970, DDT declined from a production level of 123,103,000 pounds to 59,316 pounds. The exact structure of this decline, and of the possible recovery, are not important because the registration of DDT was cancelled by EPA in 1972. The question which arises is whether this loss of DDT would have resulted in the reduction of yields, and possible losses of income, dependent on the price elasticity of demand, if farmers were not able to find substitute pest control measures.

It is possible to estimate the effect of non-availability by assessing the value of the crop produced in the post-cancellation period, and by evaluating the cost and effectiveness of selected alternatives. To make such an estimation requires data from many sources and the integration of this data in order to achieve a concise, condensed picture of the effects. Results of this type tend to be highly simplified and must be interpreted with considerable care and reservation. A diagram illustrates how different figures were introduced and applied in the benefit-cost analysis (Exhibit 1.1). This diagram shows that

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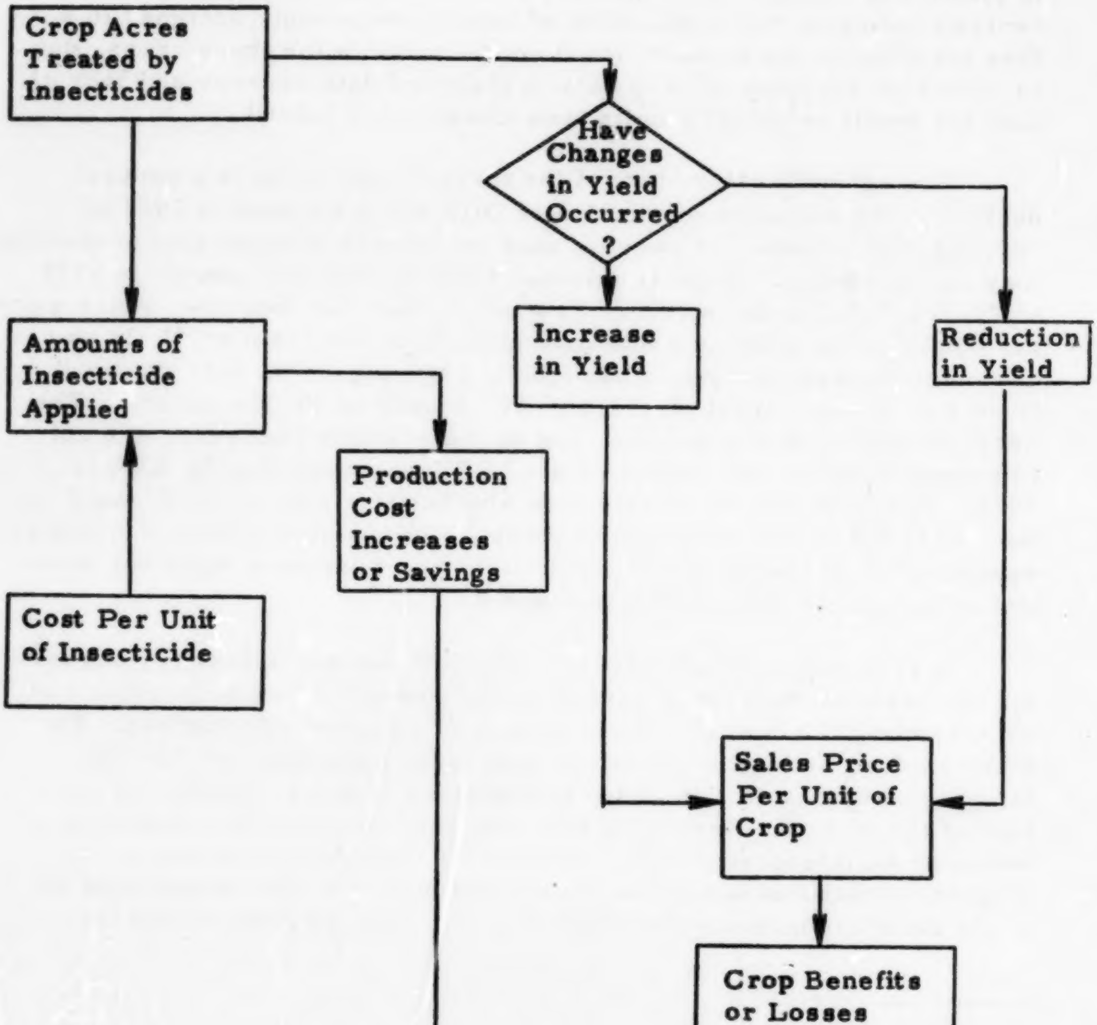
*Observation provided by the Criteria and Evaluation Division, Office of Pesticide Programs, EPA.

**U.S. Department of Agriculture, Agricultural Statistics, 1974, Washington, D.C., U.S. Government Printing Office, 1974, Table 664 and Table 665, p. 473.

EXHIBIT 1.1: Types of Data Used in Agricultural Analysis of Insecticide Benefits and Costs


Crop Acres Treated by Insecticides
Have Changes in Yield Occurred ?
Amounts of Insecticide Applied
Increase in Yield
Reduction in Yield
Production Cost Increases or Savings
Cost Per Unit of Insecticide
Sales Price Per Unit of Crop
Crop Benefits or Losses
Net Gains or Losses

many data components are required to obtain a final calculation of net gains and losses, but that in the application of the calculation procedures, some data components, such as yield changes, may be so small that they have no impact on the final calculation of "net" gains and losses.

1.2 Conceptual Problems and Assumptions

Conceptually, the period of years during which the effectiveness of two pesticides is comparatively analyzed should be the same period for each of the two pesticides only if they were introduced and used in an identical manner. Therefore, two pesticides which were introduced and registered in different years should not be analyzed during a common two-year or five-year interval. The reason for this difficulty is biological. Soon after its first season in use, the pest population, especially if they are insects, begins building an immunity to the pesticide, and the effectiveness declines as this immunity increases. The overall impact of this trend appears both in the production of crops and in the relative market positions of the two pesticides.

Specifically, the production of crops on which the older pesticide is used will decline, and crop yields on which the newer pesticide is used will increase for a few seasons, and then decline. This relative effectiveness will be reflected directly in the proportion of the total pesticide market which each one captures. If one pesticide disappears from the marketplace, other pesticides will compete for the acres to which it had previously been applied. But when farmers adopt these competing pesticides, they will not obtain an easily predictable yield. They will probably not obtain the yield that they would have obtained if the previous pesticide had not disappeared from view, nor will they obtain the yield which they would have obtained if they had been using the selected alternative pesticide for the same number of growing seasons as the number during which they had applied the now unavailable pesticide.

The above discussion implies that whenever the EPA cancels the registration of a pesticide, yields of the crops on which that pesticide had been used will increase, if a substitute pesticide is selected and applied, because there will be no residual immunity within the pest population to the newly substituted pesticide. Admittedly, if the newly substituted pesticide is vastly less effective than the cancelled pesticide, the yields obtained could be less than during the last few seasons of the previous pesticide, even though the residual immunity would have been reducing its effectiveness. But given the large number of pesticides presently registered, and the degree of overlap in registrations, it is reasonable to assert that some alternative pesticide will be available which has approximately the same basic effectiveness as the cancelled pesticide.

More realistically, the users of agricultural pesticides will respond to a registration cancellation in a more sophisticated and experimental fashion than the immediate adoption of the "next most equivalent" pesticide. The farmer's response would probably include a careful balancing of at least three variables:

- The cost of using the substitute pesticide, including the cost of the materials,
- The cost of substituting additional acres for use of a pesticide, and
- The price at which the commodity is likely to sell during the year.

If the farmer's situation indicates that he should keep his crop acres approximately constant, and that he should select a substitute pesticide for the one no longer available, and if the substitute selected is available at a cost which is a reasonable percentage of his production costs (e.g., 4 to 5 percent), then the farmer will probably treat the same acres that he had treated before.

In summary, the above discussion has shown some of the difficulties in predicting the reactions of the agricultural community in the event of the cancellation of a pesticide by the EPA. The reactions of various types of farmers could have been observed after the cancellation of DDT in 1972, but no comprehensive case study has appeared. In the absence of such a study, the simplest assumption is that farmers will select some alternative pesticide and continue to treat approximately the same acreage which they had previously treated.

In addition to the problem of whether, in reality, the farmer treats the same number of acres when he changes pesticides is the problem of whether he treats the same number of acres from year to year when he is using a single pesticide. The reason that such shifts in acreage might occur is that commodity prices might stimulate the farmer to reduce production costs and climatic factors might reduce the level of pest infestation, thus requiring less pesticide. If, however, a short period of a few seasons is analyzed, it is possible to assume that the infestation levels and other conditions remain constant, and therefore, the treatment "policy" of the farmer will remain constant, meaning that he will treat the same numberof acres with the same amounts of pesticides each season.

1.3 Interviews with Extension Agents

In order to further structure the benefit-cost analysis, it was necessary to determine what substitutions of pesticides had actually occurred after the cancellation of the registration of DDT, and what the cost implications of these substitutions were. As noted above, no comprehensive narrative or analysis of choices and trends since the 1972 cancellation has appeared, and a large-scale study of this type was outside the time frame of the present project. Therefore, a small-scale survey was conducted of extension personnel at six agricultural universities in states which are prominent in production of the three study crops.

1.3.1 Sweet Corn

Data on total weight produced are provided by Agricultural Statistics.* These production figures are divided into corn for market and corn for processing (Exhibit 1.2). The leading production state for fresh market corn is Florida and the leading producing state for sweet corn to be processed is Minnesota. A third state, Oregon, was added to the survey because, in terms of total production, the Pacific region is second only to the Lake States region, and Oregon is the largest producer of corn to be processed in the Pacific region.

The states selected thus did not include a representative state from the Corn Belt region. It should be noted that the largest production of corn to be processed in this region occurs in Illinois, but the

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*Agricultural Statistics, 1974, ibid., Table 242, p. 172.

EXHIBIT 1.2: Production of Sweet Corn by Regions, 1973

Region	Fresh Market (1000 cwt)	Production by Use Processing (tons)	Total Pounds
Northeast	3,477	78,350	504,400,000
Appalachian	555		
Southeast	5,042		504,200,000
Delta			
Corn Belt	1,374	271,100	679,600,000
Lake States	761	1,065,400	2,206,900,000
Northern Plains			
Southern Plains	160		16,000,000
Mountain	217	141,500	304,700,000
Pacific	1,357	517,650	1,171,000,000

Leading states: Fresh Market: Florida, 437,500,000 pounds;
Processing: Minnesota, 1,109,800,000 pounds.

Source: Agricultural Statistics, 1974, ibid., Table 242, p. 172.

amount is still less than one-half of the tons produced in Minnesota. The largest producing state in the Corn Belt for fresh market sweet corn is Ohio, where production is about one-fourth the amount produced in Florida.

1.3.2 Peanuts

The two major peanut producting regions are the Southeast region and the Southern Plains region.* Within these regions, Georgia and Texas are the most productive states, although South Carolina peanuts bring a higher price per pound than Georgia peanuts, and Oklahoma peanuts are produced at a higher yield per acre than are Texas peanuts. Three states, Mississippi, South Carolina, and Alabama, have shown production fluctuations in the past few years, including a drop from 1971 to 1972 and a recovery from 1972 to 1973. Alabama is second only to Georgia in production, and therefore was selected for the survey. Texas was selected as representative of the Oklahoma-Texas-New Mexico group.

1.3.3 Sweet Potatoes

North Carolina and Louisiana are well known as the two leading states in sweet potato production.** The present study, as noted above, has been defined to analyze the problem of damages caused during the time the sweet potatoes are stored after harvest but before shipment, during which period the sweet potato weevil is the principal pest. These weevils also attack in the fields, but careful control during initial planting helps to reduce this problem.

North Carolina has not been bothered by the weevil either in the field or in storage situations. Occasional infestations in the southeastern part of the state have been controlled by quarantines. Therefore, the second largest producing state, Louisiana, was selected for the survey. Generally speaking, only sweet potatoes intended for future market sales are stored, since fluctuations in demand over the year enable a significantly greater return if supplies are available for market when demand peaks. The storage may last as long as six months, although shipment after three months is more common. Any stored sweet potatoes which have suffered weevil damage during storage are considered totally unsuitable for market.

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*Agricultural Statistics, 1974, ibid., Table 175, p. 126.

**Agricultural Statistics, 1974, ibid., Table 269, p. 191.

1.4 Survey Procedures

Once the states were selected, reference was made to the USDA extension agent list* to obtain the pesticide specialist at the agricultural university in the selected state. This list gives names and telephone numbers, and these numbers were used to contact the selected agents by phone. An open, unstructured interview was conducted, during which the subject of alternatives to DDT and the prices paid for these alternatives were discussed. Although various substitutes used since the cancellation of the registration for DDT were mentioned, two in particular were frequently mentioned first: Carbaryl (Sevin)** for peanuts, and Lannate for peanuts. Methomyl (Imidan) was mentioned for use against sweet potato weevils in Louisiana. Various crop-pest combinations were mentioned, but a more precise picture of which insecticides were used against which insects is available from EPA sources*** such as the registration information (Exhibit 1.3).

Although it is difficult to obtain data on the number of acres of specific crops which were treated by a given insecticide for a specific insect, it is, in fact, possible to develop estimates of the number of acres of crops treated by a given insecticide, the amounts applied, and the cost to the farmer of these applications. Detailed procedures for developing these estimates are described in the next three sections of this report. Using these procedures and the resulting estimates, it was possible to construct a table showing the probable net costs incurred by farmers in substituting other insecticides for DDT (Exhibit 1.4).

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*U. S. Department of Agriculture, Extension Service, "List of Extension Specialists at Agricultural Universities," Washington, D.C., 1974.

**Carbaryl: 1-naphthyl methylcarbamate or 1-naphthyl N-methylcarbamate; Lannate: S-methyl N-[(methylcarbamoyl) oxy] thioacetimidate; and Imidan: N-(Mercaptomethyl) Phtalimide S-(0, 0-Dimethyl Phosphorodithioate).

***Environmental Protection Agency, Compendium of Registered Pesticides, Vol. III, Washington, D.C., 1973.

EXHIBIT 1.3: Insecticides Substituted for DDT in 1973-1974

Crop	Insect For Which DDT Was Used*	Insecticide Substituted After Cancellation**	
Peanuts	White fringe beetle	***	
	Cutworm	Carbaryl	
Sweet corn	Cutworm	Carbaryl	
	Armyworm	Lannate	Carbaryl
	European corn borer	Lannate	Carbaryl
	Corn earworm	Lannate	Carbaryl
Sweet potatoes in storage	Sweet potato weevil	Imidan	

*List provided by EPA, Criteria and Evaluation Division.

**Based on EPA Compendium and interviews with extension agents.

***No substitute identified for this insect.

EXHIBIT 1.4: National Net Costs for 1973 and 1974 Combined of Applying Substitute Insecticides Instead of DDT* (Current dollars, based on prices shown in Exhibit 2.1 below)

Insecticide	Peanuts	Sweet Potatoes (in storage)	Market Corn
Carbaryl	-$136,470 (Savings)	Not used	-$20,163 (Savings)
Lannate	Not used	Not used	$590,983
Imidan	Not used	$65	Not used

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*Exclusive of application costs.

The figures in Exhibit 1.4 show that the substitution of carbaryl for DDT will save over a hundred thousand dollars for peanuts. For sweet potatoes, the substitution of Imidan for DDT will have minimal economic impact. For market corn, the substitution of carbaryl for DDT will save over twenty thousand dollars, while the substitution of Lannate for DDT will cost over five hundred and ninety thousand dollars. The details of these results are presented in the following sections of this report.

2.0 PRICES PAID BY FARMERS FOR PESTICIDES

Estimates of the prices of pesticides used are important to the benefit-cost analysis because these prices vary from a few cents to several dollars per pound of active ingredient. The benefit-cost analysis should adequately identify all of the producers' costs associated with the substitution of an alternative for DDT. These costs occur in many forms: materials, labor, equipment, organization, and others. They arise basically in only three ways:

- If the new pesticide costs more,
- If it must be applied by a different method than the previous pesticide, or
- If a greater quantity must be applied to obtain the same results.

These costs will not change if the new pesticide has about the same price, is applied by the same methods, and is applied in the same amounts.

In the current pesticide market, prices have escalated because of intermediate shortages. Any tabulation of these prices based on earlier prices could have a serious downward bias. Therefore, data provided by EPA were used in the "1974" column of Exhibit 2. 1.

Prices shown in Exhibit 2. 1 are expected to diverge on a regional basis, except for those obtained from extension agent interviews, which are probably regional-specific. The 1974 value for DDT was calculated by averaging the three percentage price increases from 1973 to 1974 for the three other insecticides, and applying this percent (59. 3) to the 1973 national value for DDT.*

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*U. S. Department of Agriculture, Crop Reporting Board, Statistical Reporting Service, Agricultural Prices: Annual Price Summary, 1973, Washington, D.C., June, 1974 (PR 1-3, 74), p. 159.

EXHIBIT 2.1: Pesticide Prices Paid by Farmers
(Dollars per pound of active ingredient)

Pesticide	1973	1974	Percent Change
Carbaryl, 80 percent wettable powder*	1.01**	1.76****	+ 74.3
Lannate***	4.00***	10.50****	+162.5
Imidan***	8.00***	3.28****	- 59.0
DDT, 50 percent wettable powder*	0.412**	0.656	+ 59.3*****

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*Prices are assumed to be for the mixture indicated and not for the active ingredient itself.

**Agricultural Prices: Annual Price Summary, 1973, ibid., p. 159.

***Extension Agent Survey, described in Chapter 1.0. Forms of pesticides were not determined by this survey.

****Data provided by EPA, Criteria and Evaluation Division.

*****Average of percent values for the three other pesticides.

It is possible that the price given for DDT is lower than it would have been if the registration had not been cancelled. Looking back to 1968, however, the United States average price paid by farmers per pound of active ingredient was $0.373, or 3.9 cents less than in 1973.* In other words, the increase in DDT prices since 1968 has been 10.46 percent for the five-year period. In the light of this trend, the 59 percent increase from 1973 to 1974 is probably the largest reasonable increase to be expected, even with intermediate pesticide shortages.

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*Agricultural Prices: Annual Price Summary, 1973, op. cit.,

3.0 AMOUNTS OF PESTICIDES APPLIED

The total amounts of pesticides applied on a given crop depend on the rate per acre, the number of applications, and the number of acres treated. The rate per acre, in turn, depends on the recommendations of EPA and USDA, local extension agents, and the farmer's assessment of the probable infestation. The benefit-cost system concentrates on the EPA Compendium* amounts, although the USDA recommendations can be obtained from appropriate agency publications.** The results of such a review are shown in Exhibit 3.1.

Because of the possible development of immunity by specific insects, it is necessary to consider whether the rate of application per acre would increase over a period of years. Data from the two volumes of the Suggested Guide... imply that USDA continues to recommend a constant rate per acre in successive years. Therefore, the assumption for the analysis is that the rate of an insecticide application will remain constant for at least three years and probably as long as five. Since the present study is limited to a two-year period, no allowance for the development of immunity has been incorporated into the analysis. An approach to making such an allowance is described in a model developed by Hueth and Regev,*** and could be incorporated into a long-run analysis.

The rates given in the EPA Compendium (Exhibit 3.1) are the maximum registered rates for all types of applications. The Compendium, however, is sometimes unclear on the number of applications per season which are permitted at the given rate. In fact, the results of interviews with the extension agents showed that successive applications were sometimes needed. Some concrete distinctions between DDT and the substitutes emerged from these interviews in terms of numbers of applications required.

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*Compendium of Registered Pesticides, op. cit., 1972 and later revisions.

**U. S. Department of Agriculture, Suggested Guide for the Use of Insecticides to Control Insects Affecting Crops, Livestock, Households, Stored Products, Forests, and Forest Products, Washington, D.C., 1967 (Agricultural Research Service and Forest Service, Agricultural Handbook Series No. 331).

***Hueth, D., and U. Regev, "Optimal Agricultural Pest Management with Increasing Pest Resistance," American Journal of Agricultural Economics, Vol. 56, No. 3, August, 1974, pp. 543-552.

EXHIBIT 3.1: Insecticide Application Rates Per Acre
(Data are pounds of active ingredient per acre or pounds of active ingredient applied to a 50-pound crate of sweet potatoes in storage)

Crop	Insects	Insecticides			
		DDT (Before cancellation)	Carbaryl	Lannate	Imidan
Sweet Corn	Cutworm	Not recommended by USDA	2	Not registered	Not registered
	Armyworm	2*	2	0.45	Not registered
	European corn borer	2*	2	0.45	Not registered
	Corn earworm	2*	2	0.45	Not registered
Peanuts	White fringe beetle	3*	Not registered	Not registered	Not registered
	Cutworm	Not recommended by USDA	1	Not registered	Not registered
Sweet Potatoes in Storage	Weevil	0.00063 per 50 pounds**	Not registered	Not registered	0.2 ounces per 50 pounds

*USDA recommendation (Suggested Guide for the Use of Insecticides..., op. cit.)
**Obtained from extension agent survey.

For example, a total of three applications of Carbaryl for cutworms on peanuts was recommended by extension agents, making the total application three pounds per acre instead of one. Similarly, successive applications of Lannate on sweet corn were recommended, and some individual applications for multiple pests were probably also reported, boosting the total seasonal application to 6.25 pounds per acre. Finally, the amount of Carbaryl reported used on sweet corn was less than the EPA Compendium rate, i.e., only 1.66 pounds. In summary, the rates obtained in the telephone survey were:

Carbaryl: Sweet corn, 1.66 lbs/acre/season,
Lannate: Sweet corn, 6.25 lbs/acre/season,
Carbaryl: Peanuts, 3.0 lbs/acre/season,
Imidan: Sweet potatoes in storage, 0.0063 lbs/crate.

A further question in the survey enabled the determination of the rate of application of DDT to stored sweet potatoes used before 1972: about one ounce per hundred crates (5,000 pounds) or 0.00063 pounds per 50-pound crate. The rate of Imidan application was reported to be ten times that of DDT.

4.0 ACRES OF CROPS TREATED BY PESTICIDES

The number of acres a farmer treats with an insecticide is difficult to calculate. The recommended rate of pesticide per acre is relatively fixed by label requirements and by the advice of extension agents, but the number of acres treated varies with the observations of infestation by the farmer and with his hopes and expectations of a good yield.

In order to assess the benefits likely to be obtained from the use of any pesticide, and the amount of such a pesticide which is likely to be discharged into the environment, the benefit-cost system requires a procedure for calculating and forecasting the amount of a specific pesticide which will be applied to a specific crop in a given region or state. The total amount of pesticide applied can be calculated by knowing the rate per acre of application and the number of acres of the specific crop to be treated. In order to make these latter calculations, two important data sources must be used: the Census of Agriculture, published by the U. S. Bureau of the Census, and the surveys taken by USDA on farmers' use of pesticides. Although these sources do not always agree in totals, proportions from one source can be transferred to another.

More specifically, the proportion of acres of a given crop treated with a pesticide can be calculated from the USDA survey data. These proportions can be applied to the acreage totals from the Census of Agriculture to give total acres treated with general categories of pesticides for each region (Exhibit 4.1). The Census of Agriculture for the year 1969 was used in the case study for DDT, and successive censuses can be incorporated into the benefit-cost system. Since census data are not presented in crop-specific detail, it is desirable to have proportional allocating factors for distributing the total acres treated with insecticides to crop-specific insecticide combinations.

Proportional factors for crop categories are available from the acreage data provided by the USDA survey,* and these acreage data convert to the crop category proportions shown in Exhibit 4.2.

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*Andrilenas, P. A., et al., Farmers' Use of Pesticides in 1971: Quantities, USDA, ERS, Agricultural Economic Report 252, Washington, D.C., 1974; and Eichers, T. A., Quantities of Pesticides Used by Farmers in 1966, Agricultural Economic Report 179, 1970.

EXHIBIT 4.1: Acres Treated with Insecticides for Different Regions, 1969

Region Acres	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta	Southern Plains	Mountain	Pacific	United States Total
Acres treated for insects	1,399,436	2,451,513	12;165,063	4,727,749	1,793,865	3,585,356	4,168,679	5,093,610	2,448,404	4,176,185	42,009,920
Acres treated for nematodes	19,707	49,490	155,092	88,877	253,732	172,453	58,477	103,251	71,244	278,754	1,251,077
Total	1,419,143	2,501,063	11,320,155	4,816,626	2,047,597	3,757,809	4,227,156	5,196,861	2,519,648	4,454,939	43,260,997

Source: Fowler, D. L., and J. N. Mahan, The Pesticide Review, 1972, USDA, Agricultural Stabilization and Conservation Service, Washington, D.C. 20250, 1973, p. 35 (Original source of data: 1969 Census of Agriculture).

EXHIBIT 4.2: Calculation of Crop-Specific Insecticide Treated Acres in the United States, 1966 and 1971*

Crop (j) (acres in thousands)

	Peanuts		Vegetables		Field Crops	
	1966	1971	1966	1971	1966	1971
Acres of crop j which were treated by all insecticides	1,412	2,042	3,242	3,258	1,013	2,065
Total acres of all crops treated by all insecticides	67,210	89,248	67,210	89,248	67,210	89,248
Proportion of acres of crop j to total acres of all crops treated by all insecticides	0.02101	0.02288	0.02484	0.03651	0.01507	0.02314
Average proportion FC_j of two years of data	0.02195		0.03067		0.01910	

*FC_j = proportion of the total number of acres in the United States, to which insecticides have been applied for crop j during a given year.

Source: Eichers, T., op. cit., 1970, pp. 53-55; and Andrilenas, P. A. op. cit., 1974, pp. 48-50.

One of the crop categories contained in the USDA survey analysis is "peanuts" so that, for the DDT case study, acreage data can be obtained directly by applying the proportion factors for that category to the Census of Agriculture acres. For the other two crops required in the DDT case study, market sweet corn and sweet potatoes, further calculations are required in order to allocate the acres given in the categories "vegetables" and "field crops" among these specific crops.* The only data available to make this allocation was from the annual issues of the Agricultural Statistics, 1974 (op. cit., pp. 153, 171, 191). The 1974 issue gives acreage harvested in 1969 for most of the specific vegetable crops contained in the USDA insecticide survey of 1971. Therefore, it is possible to total the acres harvested for the vegetable and field crop groups, and then calculate the proportion of acres harvested for market sweet corn and sweet potatoes (Exhibit 4.3). The acres treated for the ten USDA agricultural regions are shown in Exhibit 4.4.

Thus far, as shown in Exhibit 4.4, the numbers of acres treated by all insecticides have been calculated for ten agricultural regions and three specific crops. The next requirement is that the number of acres treated by DDT for each region be obtained. Although crop-specific data for each insecticide are not given in the USDA surveys, the proportions of acres treated in a specific region by each specific insecticide can be calculated, and applied to acreage data for each specific crop. These proportions and the resulting acreages are shown in Exhibit 4.5.

The data shown in Exhibit 4.5 were rounded to the nearest hundred acres and because of the successive proportional allocations, they probably represent somewhat smaller acreages than were actually treated by DDT in 1969. Thus, it is surprising to see that less than 50 acres of sweet potatoes were treated by DDT in 1969 in the Appalachian region, one of the largest sweet potato producing regions. Nevertheless, the proportion of field crops which constitute sweet potatoes is relatively small and the 1971 survey showed only 49,000 acres of all field crops nationwide were treated by DDT.**

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*See list of crops, p. 22 of P. A. Andrilenas, et al., op. cit.

**Andrilenas, P. A., et al., op. cit., Table 14, p. 49.

EXHIBIT 4.3: Data for Allocating Acres Treated from Crop Categories to Specific Crops for the United States, 1969

Acres Harvested (in thousands)

A Field Crops	B Vege-tables	C Sweet Potatoes	D Market Corn	C/A[5]	D/B[5]
6,693[1]	3,333[2]	136.9[3]	637.8[4]	0.02045	0.19136

[1] Figure compiled using crops named in list given by: P. A. Andrilenas, et al., op. cit., 1974, Appendix 1, pp. 22-23; and data from Agricultural Statistics, 1971. However, data not available for buckwheat, castor beans, lentils, millet, mung beans, sesame, spelt, sunflowers, velvet beans, and cowpeas, so that total includes acres for grass and hayseed, peppermint, spearmint, hops, rutabagas, dry beans, dry field peas, flax, popcorn, broomcorn, sugar cane, and sweet potatoes only.

[2] Agricultural Statistics, 1974, Table 215, p. 153.

[3] Agricultural Statistics, 1974, Table 269, p. 191.

[4] Agricultural Statistics, 1974, Table 241, p. 171.

[5] These ratios are the proportion of "vegetables" which are sweet potatoes and market corn. The data are acres harvested but must be used to derive acres treated from acreage data not available in disaggregate form.

EXHIBIT 4.4: Allocation of Acres Treated by all Insecticides in the United States, 1969 (Acres in hundreds)

	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta	Southern Plains	Mountain	Pacific	United States Total
Peanuts	623	1,098	4,968	2,114	899	1,649	1,855	2,281	1,106	1,955	18,987
Field crops	271	477	2,162	920	391	718	807	993	481	851	8,263
Vegetables	435	767	3,472	1,477	628	1,153	1,297	1,594	773	1,366	13,268
Sweet potatoes	6	10	44	19	8	15	17	20	10	17	169
Market corn	83	147	664	283	120	221	248	305	148	261	2,539

EXHIBIT 4.5: Specific Crop Acres Treated with DDT for Different Regions
(Based on 1969 data and 1971 survey factors)

Regions (Data in hundred of acres)

	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta	Southern Plains	Mountain	Pacific	United States Total
Proportion*	.00815	.00124	.00043	--	.04108	.09527	.12729	.03499	.01095	.00551	
Peanuts	5	1	2	--	37	157	236	80	12	11	
Sweet potatoes	--	--	--	--	--	1	2	1	--	--	
Market corn	1	--	--	--	5	21	32	10	2	1	

*These proportions obtained from P. A. Andrilenas, et al., op. cit., 1974, Table 15, Appendix II, p. 51.

The above discussion describes how the benefit-cost system approaches the calculation of acres of a specific crop, for each state, which are treated by a specific insecticide, but the calculations described are only for one year, the year in which the Census of Agriculture was taken (1969). The benefit-cost system requires the capability of selecting any year or period of years, since the registration period for pesticides is five years. This capability must include the option of selecting five years in the future, for proposed new pesticides, as well as five years in the past, for the comparison analysis of similar pesticides.

A simplified procedure for updating the 1967 survey acreage to 1973 and 1974 was devised using the preliminary USDA 1985 forecasts.* The crop category forecast factors were calculated after interpolating the acreage amounts between 1969 and 1975, as shown in Exhibit 4.6, and the results of applying these forecast factors to acreage-treated data are shown in Exhibit 4.7.

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*Smith, Allen, et al., Projections of the U. S. Farm Subsector and Policy Implications, USDA, FRS, National Economic Analysis Division, Washington, D.C., 1974, p. 31.

EXHIBIT 4.6: Forecast Factors for Acres Treated by DDT in the United States

Assumption: Forecast of acres harvested will forecast acres treated by DDT.

Thousands of Acres

	Peanuts	Sweet Potatoes	Vegetables
1969	1,456[1]	136.9[3]	3,333[4]
1970-1972	1,469[2]	119.0[2]	3,580[2]
1973	1,496[1]	113.0[3]	3,338[4]
Ratio 1973/1969	1.02747	0.82542	1.00150
1974[5]	1,518	112.0	3,364
Ratio 1974/1969	1.04258	0.81812	1.00930
1985	1,757[2]	95.0[2]	3,648[2]

[1] Agricultural Statistics, 1974, Table 174, p. 125.

[2] Smith, A., et al., op. cit., 1973, Table 12, p. 31.

[3] Agricultural Statistics, 1974, Table 269, p. 191.

[4] Agricultural Statistics, 1974, Table 215, p. 153.

[5] All 1974 figures interpolated between 1973 and 1985.

EXHIBIT 4.7: Acres Treated by DDT for Different Crop for Different Regions, 1973-1974 (acres in hundreds)

	North-east	Lake States	Corn Belt	North-ern Plains	Appa-lachian	South-east	Delta	South-ern Plains	Moun-tain	Pacific	United States Total
1973											
Peanuts	5	1	2	--	38	161	243	82	12	11	555
Sweet potatoes	--	--	--	--	--	1	2	1	--	--	4
Market corn	1	--	--	--	5	21	32	10	2	1	72
1974											
Peanuts	5	1	2	--	39	164	246	83	13	12	565
Sweet potatoes	--	--	--	--	--	1	2	1	--	--	4
Market corn	1	--	--	--	5	21	32	10	2	1	72

Two-year totals -- peanuts: 1,120; sweet potatoes: 8; market corn: 144.

5.0 TOTAL AMOUNTS OF INSECTICIDE APPLIED

The results of the preceding discussion were the total number of acres of each of three crops which would have been treated by DDT in 1973 and 1974 if the registration of that insecticide had not been cancelled. The final step in calculating the total amount of insecticide applied is to multiply the rate per acre for peanuts and sweet corn by the number of acres treated (Exhibit 5. 1).

Sweet potatoes present a different situation since the number of acres treated is not directly tied to the number of pounds in storage. The amount of sweet potatoes in storage in 1974 was provided by the EPA, Criteria and Evaluation Division and, since production varied only 0. 6 percent from 1972 to 1973, it is plausible to assume that production totals will not vary enough to change the resulting storage quantity. The amount determined by the Criteria and Evaluation Division was 47, 600 pounds, or 952 fifty-pound crates. The final cost calculation requires multiplying the total pounds applied by the cost per pound determined in Chapter 2. 0 above. The results of these calculations are shown in Exhibit 5. 2.

EXHIBIT 5.1: Pounds of Insecticide Applied, United States
(Acres obtained from Exhibit 4.7 above)

		Peanuts		Sweet Potatoes in Storage***		Market Corn	
		1973	1974	1973	1974	1973	1974
Carbaryl	rate	3.0 lbs/acre*		Not registered		1.66 lbs/acre*	
	total lbs	166,500	169,500			11,952	11,952
Lannate	rate	Not registered for crop		Not registered for crop		6.25 lbs/acre*	
	total lbs					45,000	45,000
Imidan	rate	Not registered for crop		0.0063 lbs/crate*		Not registered for crop	
	total lbs			6	6		
DDT	rate	6.00 lbs/acre (assume 2 applications)		0.00063 lbs/crate*		4.00 lbs/acre (assume 2 applications)	
	total lbs	333,000	339,000	1	1	28,800	28,800

*Extension agent survey (see Chapter 3.0 above)
**EPA compendium.
***One crate of stored sweet potatoes equals 50 pounds. The storage amount of 952 crates was determined by EPA.

EXHIBIT 5.2: Costs to Farmers of Total Pesticides Applied (current dollars)*

Note: Data for different pesticides are alternative courses of action, except for DDT.

	Peanuts (dollars)		Sweet Potatoes (dollars)		Market Corn (dollars)	
	1973	1974	1973	1974	1973	1974
Carbaryl	209,790	372,900	Not registered for crop		15,060	26,294
2-year total	582,690				41,354	
Lannate	Not registered for crop		Not registered for crop		180,000	472,500
2-year total					652,500	
Imidan	Not registered for crop		48	20	Not registered for crop	
2-year total			68			
DDT	274,392	444,768	1**	2***	23,731	37,786
2-year total	719,160		3		61,517	
Net costs of substitution for DDT	Carbaryl -136,470		Imidan 65		Carbaryl -20,163 Lannate 590,983	

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*Exclusive of application costs.

**Actually less than 1 dollar.

***Actually less than 2 dollars.

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